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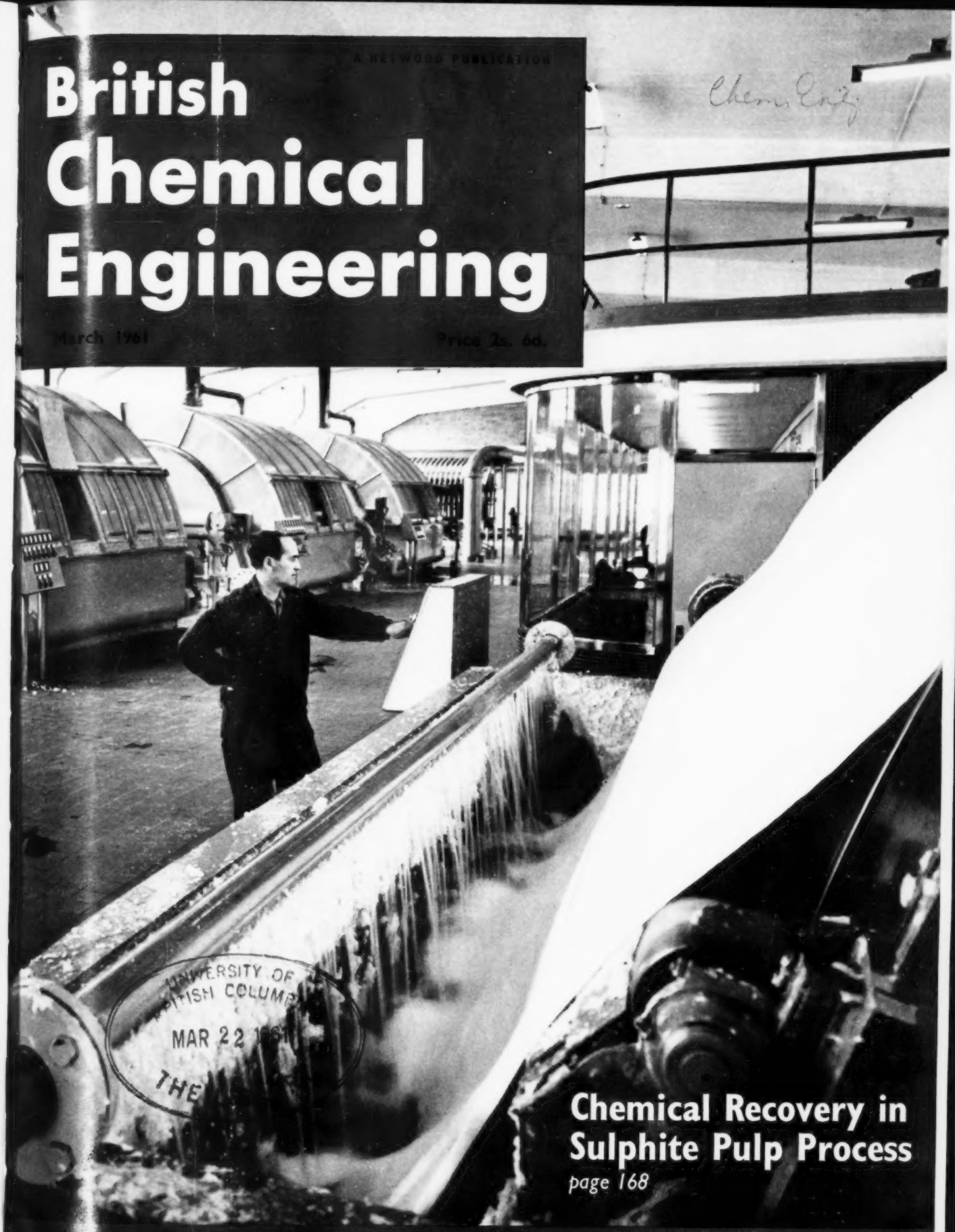

UNIVERSITY OF BRITISH COLUMBIA
MAR 22 1961
THE

Chemical Recovery in Sulphite Pulp Process

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Optimal Design of Bubble-cap Trays (page 158) Corrosion Resistance of Metallic Coatings (page 172)
Particle Distribution in Fluidisation—Part II (page 176) Bulk Supply of Chemicals (page 190)

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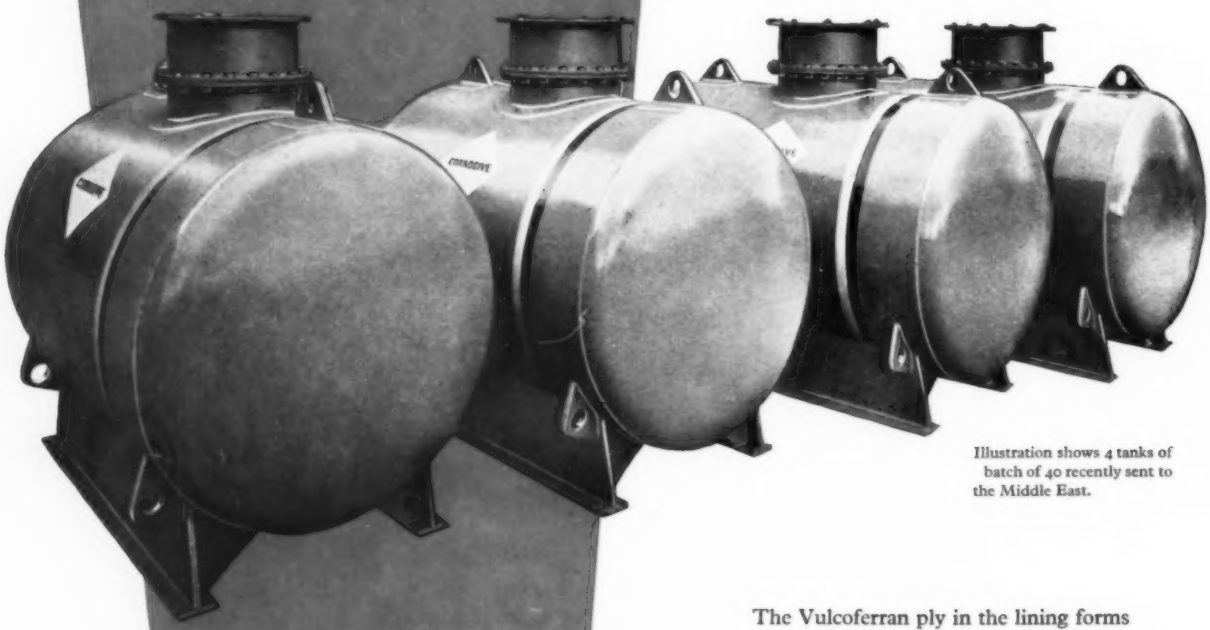

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DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

Ultrasonic Homogeniser Performance

IT is only within the last 12 or 13 years that emulsification by ultrasonic vibration has become a practical proposition. Among the pioneers of this principle in Britain are Ultrasonics Ltd. of Otley, Yorkshire, inventors and makers of Rapisonic and Minisonic homogenisers. These generators are also being made in the United States by Ultrasonics' sister company, the Sonic Engineering Corporation; and one of the Sonic-built Minisonic homogenisers has recently been the subject of an interesting evaluation* carried out by ROBERT E. SINGISER at the University of Connecticut.

The object of the investigation was to compare the performance of a conventional homogeniser, the model QV-6-1 Eppenbach Colloid mill, with three ultrasonic generators—the General Electric piezo electric-type ultrasonic generator with a quartz crystal; the Branson Ultrasonic Corporation's Sonogen piezo-electric generator driving a barium titanate tank-type transducer; and the Minisonic Mark 2 hydrodynamic-type ultrasonic generator. Emulsions of 25 per cent mineral oil, peanut oil and safflower oil, each made with four different emulsifiers, were exposed in each apparatus for periods up to 15 minutes. The best of these emulsions were analysed after zero, 15, 30, and 60 days storage. From the size frequency analysis data, specific interfacial area, mean globule diameter and *standard deviation* were calculated.

Of the four homogenisers tested, only the Eppenbach colloid mill and the Minisonic generator were adaptable for production use. The emulsions produced by the Minisonic generator were distinctly superior to those made on any other apparatus, with a smaller mean globule diameter and much greater uniformity.

*Journal of the American Pharmaceutical Association, 1960, 49, 7, p. 482.

Steam Power from Waste Pulp Liquors: Norwegian Plant Operates Zimmermann Process

A STEAM power plant operating on organic waste liquors—believed to be the first large-scale plant of this type in the world—has been installed at Sarpsborg, Norway, by Aktieselskapet Borregaard, one of the leading Norwegian pulp and paper manufacturers.* The plant utilises the Zimmermann process patented and developed by Sterling Drug Inc. in the U.S.A.

In the Zimmermann process, a heated mixture of waste liquors and water under pressure is oxidised by a stream of compressed air, resulting in a low-temperature combustion process in which some of the water is converted into steam and hot gases are generated in the form of combustion products.

In the Norwegian plant, which generates 236,000 lb of process steam per hour, the reaction is carried out in a 75 ton reactor, 68 ft long and 7 ft in diameter. The vessel is made of Type 316 19/9 Cr-Ni-Mo stainless steel. The steam/gas mixture from the reactor is expanded through a steam turbine after which it is flashed into steam in a series of separators and used for various process duties. The liquid residue in the reactor is also fed to separators and heat exchangers to produce steam and hot water.

The reaction is not self-starting: the process is to charge the reactor with liquid under pressure, heat it to a temperature at which rapid oxidation will occur, and then to supply compressed air. Soon the reaction generates sufficient heat to sustain itself. Typical operating temperatures on waste pulp liquor are 260°-315°C, with air and liquor pressures of the order of 1400-1500 psi.

Advantages of the Zimmermann process are that, in addition to saving fuel costs, it prevents pollution by discharged waste and makes possible recovery of any valuable organic materials in the waste. Efficiencies up to 95 per cent are obtained through the direct heat exchange between the burning combustibles and water. The water content of the waste liquor is an essential element in the process, and thus evaporators, concentrators and dryers are eliminated.

**Inco—Mond Magazine* No. 16, p. 10.

Data Handling System for a Processing Line

WITHIN the last few years many schemes for the automatic data-handling of production processes have been put into practice.

The basic idea of the recently described Tallimarker system* which was developed in the first place for tallying individual ingots through the various processes in a rolling mill, is to provide a complete scheme of information handling for a manufacturing process without the need for any written records; the component being processed is identified and its history presented at each stage in the production line. The scheme calls for:—

(1) Information-input stations at key points along the production line;
(2) Information-output (display) stations at the same or other key points; these inform the operator of what he needs to know about the product, or what has just been done to the product;
(3) Central information store;
(4) Read-out and print-out facilities at a production office.

The information store accumulates information from the input stations and is the source from which the display stations and final print-out are fed. The read-out and print-out facilities take over each "full" information storage channel in turn, cause it to print-out its information, empty it of information, and return it for further use.

In the prototype model Tallimarker, information input is by pushbuttons—but could equally well be by other forms of digital input, e.g., true time, performance records, counts, analogue-digital converter data, etc. Information is stored on uniselectors and relays, the number of channels or levels in the store being at least equal to the number of components which can be processed simultaneously. Synchronism is maintained throughout so that all the information on one item

being processed is stored in a single channel. Information is displayed on digitrons.

For ease of maintenance, unit construction is employed, and the information store is unaffected by power supply failure. The Tallimarker system can be made to provide the operators at the various stations with instructions tallying with the flow of components, giving the possibility of centralised control of the whole processing line.

*W. L. Marks and D. J. Mayes. *Society of Instrument Technology*, January 11, 1961.

Welding Techniques in the U.S.S.R.

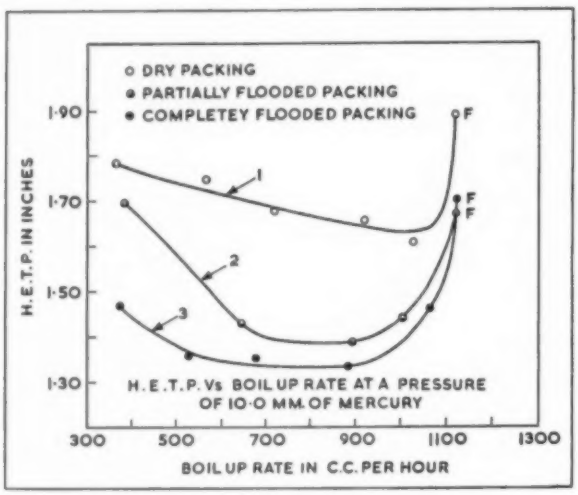
IN the Soviet Union, there is closer liaison between research, development, production, and the training of welding personnel and supervisors than in Britain; and the emphasis is on applied rather than on fundamental research. New processes and machines are much more readily available to industry than is the case in Britain. These are some of the points observed by a team from the Institute of Welding which visited the Soviet Union in September 1960.

Among the newer techniques which particularly impressed the British team were friction welding, a low-power process applicable only to workpieces of circular profile, in which fusion is attained by the mechanical rotation of one part against another; and diffusion welding which is used for joining metallic and non-metallic materials. Diffusion welding is carried out in a vacuum, the clean surfaces of the components being brought together under heat and pressure, resulting in the atoms diffusing across the joints to produce an alloy.

Knitmesh Packing at Reduced Pressures

A POSSIBLE advantage of pre-wetting knitmesh packing in a fractionating column when operating at reduced pressure has been brought to light by L. G. Miskin and M. S. Qureshi, of the Department of Chemical Engineering, University of Birmingham*. Their investigations were concerned with the performance of Multiful 8 stainless steel packing in a 1½ in diameter fractionating column at pressures of 10 and 50 mm Hg.

The illustration, which shows how the H.E.T.P. values vary with boil-up rate when operating at 10 mm Hg, demonstrates how wetting the packing improves the performance at reduced pressure. (At the higher pressure, there was also some improvement due to wetting, but much less marked). The top curve represents fractionation without any pre-wetting of the packing. The middle curve was obtained after 30 min of incipient flooding. The bottom curve shows ultimate fractionation after incipient flooding had been continued until no further improvement took place.



At 10 mm Hg the H.E.T.P. values go through a minimum and rise at low boil-up rates. This may be due to a change from turbulent to streamline flow. Also liquid viscosity increases as the pressure drop and temperature is lowered.

Curves showing the relationship between dynamic holdup and boil-up rate were also plotted. At both pressures, the "dry" and "pre-wetted" curves crossed at a hold-up of about 8 vol. per cent, the dry packing showing a higher hold up in the regions of low boil-up rate.

The investigators suggest that these results are probably explained by non-uniform liquid distribution in the dry packing.

**Birmingham University Chemica Engineer*, Summer 1960, p. 45.

Reduction of Powdered Iron Oxide in Vertical Flow Reactor

ONE of the drawbacks encountered on the commercial scale in fluidized-bed processes for the reduction of powdered iron oxides is sintering of the iron, which seriously interferes with fluidization. A technique which may make it possible to avoid such sintering has been used in studies of the mechanism of the reduction process by a number of workers in the Chemical Engineering Department of the University of Minnesota*.

Using a small vertical flow reactor, W. A. Lloyd and N. R. Amundsen found that iron oxides entrained in hydrogen and reduced during transport through an electrically heated tube, released more than 90 per cent of their oxygen in 2 to 15 seconds. No sintering difficulties occurred. On a larger scale, I. G. Dalla Lana and N. R. Amundsen also encountered no sintering difficulties in a tubular vertical flow reactor, comprising a 26 ft long stainless steel tube of which 20 ft was covered with electrical heaters, and the reaction zone extended over 16.1 ft. Their experiments were carried out at temperatures ranging from 450°C to 600°C.

Because sintering is a rate process influenced by temperature, these investigators suggest that, during reduction in the flow reactor, a particle may be reduced and leave the reactor before appreciable sintering can take place. Also, because the solid phase is in streamline flow and therefore very dilute, there is less tendency for particle interaction in the flow reactor than in a fluidized bed.

**Industrial and Engineering Chemistry*, January 1961, p. 19 - 22.

Thin Tube Plates for High Pressure Heat Exchangers

THE use of very thin tube plates in high-pressure heat exchangers has recently been investigated both theoretically and experimentally*. The *ad hoc* experimental results indicate that thin tube plates are much stronger than analysis based on elastic theory would suggest.

Two tests to destruction were carried out on small complete heat exchangers. One comprised 159 mild steel tubes ¼ in OD by 30 s.w.g., 13½ in long, with tube plates in mild steel 0.028 in thick, contained in a 5 in bore ¼ in wall mild steel shell. Under hydraulic pressure tests, no leakage occurred until a pressure of 1450 psi was reached—2.4 times the estimated pressure to cause failure. In the second test, 38 stainless steel ¼ in by 18 s.w.g. tubes were used with stainless steel tube plates 0.036 in thick: in this case, the actual pressure to failure was 4.4 times that estimated. Static tests of thin metal strip in bending showed that deflections 70 times as great as those estimated at failure could be withstood.

It seems probable that, if systematic experiments were carried out, the results could readily lead to the development of a plastic-strain design method for thin tube plates.

*D. E. Hartley, *Nuclear Engineering*, December 1960, 557, and January 1961, 8.

FLOW CONTROL NEWS
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Designed expressly for ½ in. and ¼ in. pipes over C_V range 3.0 to 0.00008, Minim flow valves are manufactured by Research Controls Inc. of Tulsa, Oklahoma, U.S.A. (Sole Agents in Great Britain: G. A. Platon Ltd.).

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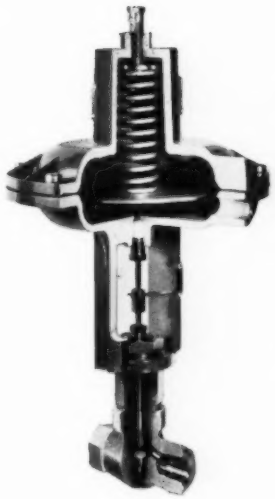

These miniature control valves are fitted with valve position indicators and are made in materials for all industrial fluids at any temperatures and pressures.

Minim valves are particularly suitable for use in Pilot Plants, Research Laboratories and Process Industries, or wherever space and low flows necessitate the use of miniature equipment. All accessories (normally associated with larger valves) are available on Minim flow valves, also special finishes for contaminated atmospheres.

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THE MISSING FLOSTAT joins the range

The introduction over the past few years of the Flostat series of flow-powered automatic flow controllers has, hitherto, not included an instrument of intermediate size.

Now, filling the gap between the Flostat Minor and the range of Industrial Flostats (1 in., 1½ in. and 4 in.), is the new Half Inch Flostat for the control of flows in the range: 5-120 g.p.h. Water, and 20-500 c.f.h. Gas. It is for pipe mounting, but has screwed connections.

The Half Inch Flostat has the balanced (double-beat) valve of the larger models but is lighter and more compact. It incorporates a control setting adjustment device (Type V) which can be factory-set and locked when desired.

This new instrument now enables the benefits of Flostat Control to be further extended in a wide range of applications, e.g. Blending, the distribution of Service Fluids, and the control of Fixed Feeds.

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Symposium on the Application of Analogue Computers

TO provide an insight into the applications, scope and limitations of analogue computers, is the main purpose of a two-day symposium organised by the Departments of Electrical, Mechanical, Aeronautical and Chemical Engineering of the Loughborough College of Technology.

The symposium will commence at 11 a.m. on Monday, April 10, 1961, and the first day will be devoted entirely to introductory lectures on Analogue Computing Techniques. On Tuesday, April 11, specialist lecturers from industry and computer manufacturers will discuss applications of computers in various industries and future trends.

Applicants may enrol for either of the two days or both. Overnight accommodation on the Sunday and Monday nights is available. Fees range from 3 guineas, including lunch, for a single day to 6½ guineas with two days' accommodation.

Basalt Advances as a Material of Construction

THERE is an abundance of basalt rock in Czechoslovakia and its excellent resistance to abrasion and acidic media is leading to its widespread use as a material of construction in that country and elsewhere. Like glass, it melts at a temperature in the vicinity of 1250°C and the type of cooling which the molten mass undergoes determines whether this material becomes a vitreous or crystalline solid.

In the recrystallised form, basalt has properties superior to those it possessed in its original state; for example, its abrasion resistance is enhanced and exceeds that of iron and steel severalfold. The following are some properties of recrystallised basalt: ultimate strength, 360 kg/cm^2; compressive strength, 5500 kg/cm^2; hardness 8.5 Mohs scale; thermal conductivity, 0.7 kcal/m^2 hr °C.

Examples of its use displayed by Czechoslovak Ceramiks at the Brno Fair were tiles for chemical plant floors, pipe and vessel linings, bends and tees for the pneumatic or hydraulic conveying of solids, and linings for conveyors, cyclones and ball and rod mills. A noteworthy application is for the handling of acid slimes (pH 3-5) at pyrites plants.

At present steel pipes of from 80-500 mm in diameter are being lined with basalt; bends are available in 0.75-3 m. In addition flat tiles of sizes ranging from 200 x 200 x 20 mm to 250 x 250 x 40 mm are in production, the thicker sizes being supplied with cast-in-studs; curved tiles, half-round or angled at 120°, were also shown, which, with straight tiles, can be built up to form chutes.

Linear Induction Pump Performance

ELECTROMAGNETIC pumps—still relatively new and not yet thoroughly amenable to performance prediction—are becoming increasingly important in the investigation and application of liquid metals as reactor fuels. With the object of developing a small linear induction electromagnetic pump suitable for operating a high temperature liquid metal test loop, a performance investigation* has recently been carried out for the United States Atomic Energy Commission at the Ames Laboratory of the Iowa State University of Science and Technology, on a two-pole three-coil Y-connected three-phase pump, mercury was used as working fluid.

General conclusions from the results of the test emphasise the importance of minimising the pump air gap while maintaining a duct thickness consistent with good hydraulic efficiency. The phenomenon of fluid wetting of the pump duct wall and the use of side bars (for reducing resistance to eddy currents in the fluid) provide powerful tools for improving performance of the linear induction pump. Full advantage of the improved performance can be obtained if the hydraulic losses are minimised by using a pump section with large duct width, which also improves the power factor and decreases the phase current requirements of the pump.

* Chemistry-General (UC-4) TID 4500, Research and Development Report, August 1960. Ames Laboratory at Iowa State University of Science and Technology.

Agglomerate Mixing for Uniform Powders

A METHOD which has been developed for the intimate blending of reproducible heat and delay powders used in ordnance devices may have many other applications where the objective is the production of intimate and reproducible fine powders.* The three basic requirements of this method are:— (1) a suspending fluid in which particles do not disperse but form agglomerates naturally. This agglomerating tendency must persist after the mixture is dried and when the components are being blended; (2) particles whose size is well below the agglomerate diameter; (3) a mechanical method of mixing the particles.

Suitable mixers include ball mills, colloid mills and high-speed kitchen blenders, which all produce liquid shearing forces that break agglomerates into individual particles and allow them to mix together. As soon as the particles move out of the region of liquid shear they re-agglomerate as particles of the mixture, not as individual components.

Satisfactory suspending fluids, which are selected according to a trial and error method, include toluene, ethyl acetate and water. In water suspensions, agglomeration is generally adversely affected by a high zeta potential, caused by the absorption of ions on the particle surfaces. Pure organic non-polar vehicles have been used for blending a number of inorganic compositions whose particles do not disperse readily in liquids of this type, and the possibility of coating powders with a chemisorbed layer of molecular thickness may be considered if all other methods of inducing agglomeration fail.

*Raymond H. Comyn, Ira R. Marcus, and Robert E. McIntyre, *Industrial and Engineering Chemistry*, December 1960, 995.

Analysing Propellent Mixtures by Radioactive Tracers

MORE rapid and more accurate determination of the weight percentage of an ingredient, such as an oxidiser, in a composite propellent mixture is possible by using a radioactive tracer technique than by conventional chemical analysis. A method of using radioisotopes for this purpose offers an accuracy of better than 0.5 per cent in the weight analysis of propellent constituents.

The radioactive tracer used was I^{131}, in the form of monoiodobenzene, with a half life of 8.08 days. Sodium iodide, thallium activated, crystals in conjunction with a photomultiplier tube and an electronic scaler were used to take scintillation counts. The weight of the ingredient was found from

$$W_o\% = 100 \left[1 - \frac{SA_p}{SA_f} \right]$$

where $W_o\%$ = percentage weight of the ingredient
SA_p = specific activity of the propellent after adding the ingredient
SA_f = specific activity of the pre-mix fuel or other ingredients.

THE PROBLEM OF CORROSIVE VAPOURS

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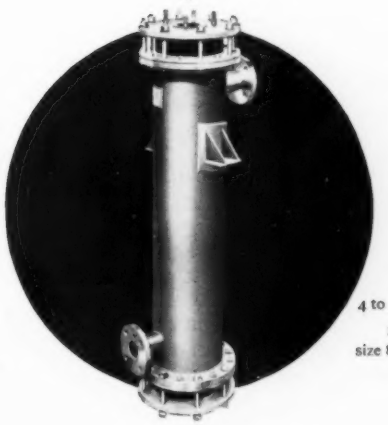

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The addition of 3 millicuries of monoiodobenzene per 100 lb of propellent yields a propellent sample count in the desired range of 500,000-600,000 counts a minute for a 4-dram sample.

Finally, in order to use this method effectively, and to ensure accurate counting, R. A. PETERSON*, who described the technique, makes a number of recommendations. For example, an all-electronic scaler and timer should be used and 500,000 counts per sample should be taken.

*Paper read to the December 1960 meeting of the A.I.Ch.E.

Finding Leaks in Refrigerating Installations

IN sealed refrigerating systems including many industrial installations, the allowable leak rate is so small that it requires very sensitive instruments to measure it. Various ways in which this can be done have recently been reviewed.*

A simple but sensitive method, capable of detecting leaks as small as 6×10^{-4} lusecs, is to spray the installation with a red solution of agar-agar (1 part), anhydrous soda (0.1 part), phenolphthalein (0.15 part), in 40 parts of distilled water, and to pressurise the installation with carbon dioxide. At a leak, the carbon dioxide reacts with the agar-agar to produce a white spot, the diameter of which indicates the leak rate. The same method can be used with ammonia or ammonia/air mixtures as the compressing gas. Alternatively, a brushed-on white paste of barium sulphate, water, glycerine and phenolphthalein can be used to detect ammonia leaks, in this case the leak being indicated by the appearance of red dots.

An apparatus for warning the operator of leaks in ammonia evaporators, developed by the Nederlandse Vereniging voor Koeltechniek, is based on a reaction between ammonia and hydrochloric acid producing white fumes. These are detected by a photocell controlling a warning relay, the sensitivity of the instrument being 0.5 p.p.m.

Where the refrigerants are halogenated hydrocarbons, the halogen torch is often used, and has sensitivities up to 10^{-2} lusec. Where the refrigerant is miscible with oil, leaks can be found by mixing in certain mineral oils which have the property of fluorescing under ultra-violet light. With this method sufficient time must be allowed before testing for some oil to escape.

Detectors of High Sensitivity

Higher sensitivities up to 2×10^{-4} lusecs can be attained with electronic halogen leak detectors, which are based on the fact that if a hot platinum anode (700°-800°C) is arranged to face a tubular cathode at a potential around 200V, a measurable current of positive ions flows, which current is greatly increased when halogens are present. This method of leak detection is probably the most suitable for industrial use.

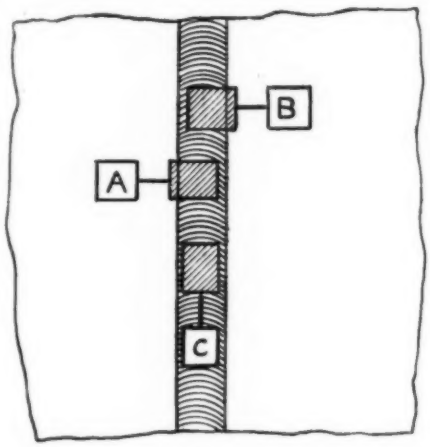
Vacuum methods are also in use for testing refrigerating systems. Vacuum meters are usually sensitive to the type of gas in the installation. If the installation to be investigated is sprayed, after evacuation, with, say, hydrogen gas, the hydrogen will enter the leak and will affect the meter reading to an extent greater than the actual pressure change. In the case of the palladium-ionisation meter, the manometer reacts only in the presence of hydrogen and sensitivities of 10^{-4} lusec can be obtained.

Mass spectrographs of very high sensitivity, capable of detecting leak rates of 7.6×10^{-6} lusec, have been used for checking hermetically sealed cooled units. The mass spectrograph is attached to an evacuated system, which is sprayed with helium so that any helium entering through a leak is detected by the mass spectrograph. Because of the great sensitivity of this type of apparatus—which has a high first cost—leak tests can be carried out in a relatively short time, and it is therefore favoured for production testing of mass-produced units.

*J. A. KNOBBOUT, *Journal of Refrigeration*, November/December 1960, 136.

Automatic Ultrasonic Inspection of Pipe Welds

FOR the continuous inspection of longitudinal seams in welded pipes, either during manufacture or subsequently, automatic ultrasonic scanning equipment has been developed by Röntgen Technische Dienst in Holland, capable of testing at speeds of 6 ft per second. Two forms of the apparatus are available: for use in the rolling mill, the ultrasonic probe mechanism is stationary and the pipe is traversed along it. For field inspection of welded pipes, a moving ultrasonic scanning unit is traversed along the stationary pipe. The equipment is used in conjunction with a USIP 10 Ultrasonic flaw detector and a monitor designed by DRS. J. and H. KRAUTKRAMER, who are represented in Great Britain by Solus-Schall Ltd.



The automatic scanning apparatus works as follows: probes A and B search for longitudinal flaws such as cracks and incomplete penetration, while probe C scans for transverse tracks, piping and inclusions. The gate of an electronic monitor is used to give audible or visual warning when a longitudinal flaw is detected, or to operate a paint-spray gun to mark the position of the flaw on the pipe. The gate appears on the cathode ray screen as an interruption of the time base, and is adjustable both in length and position. When correctly set, it covers that part of the time base which corresponds to the weld seam plus a small extension into the parent metal on the far side of the weld, facing the probe. Flaw echoes occurring within the gate will trigger the alarm system. A second gating system is used to give warning of transverse flaws. A double-channel pen recorder can also be used to record position and height of longitudinal and transverse flaws.

Theory for Transient Behaviour of Distillation Column

THE problem of controlling a distillation column is essentially that of minimising fluctuations in the output streams arising from transient disturbances in the input streams. Currently, most control systems in the process industries are designed by empirical or semi-empirical methods which may produce results far from the optimum, consequently much effort is now being spent to evolve better methods. Recently, for example, a new and powerful method for calculating the variation in all output variables resulting from any input has been developed*.

In this method, an iterative one, any number of trays can be considered by the repetition of a series of simple steps; the method is thus eminently suited to digital computer application. The method can deal with multiple feeds or take-offs,

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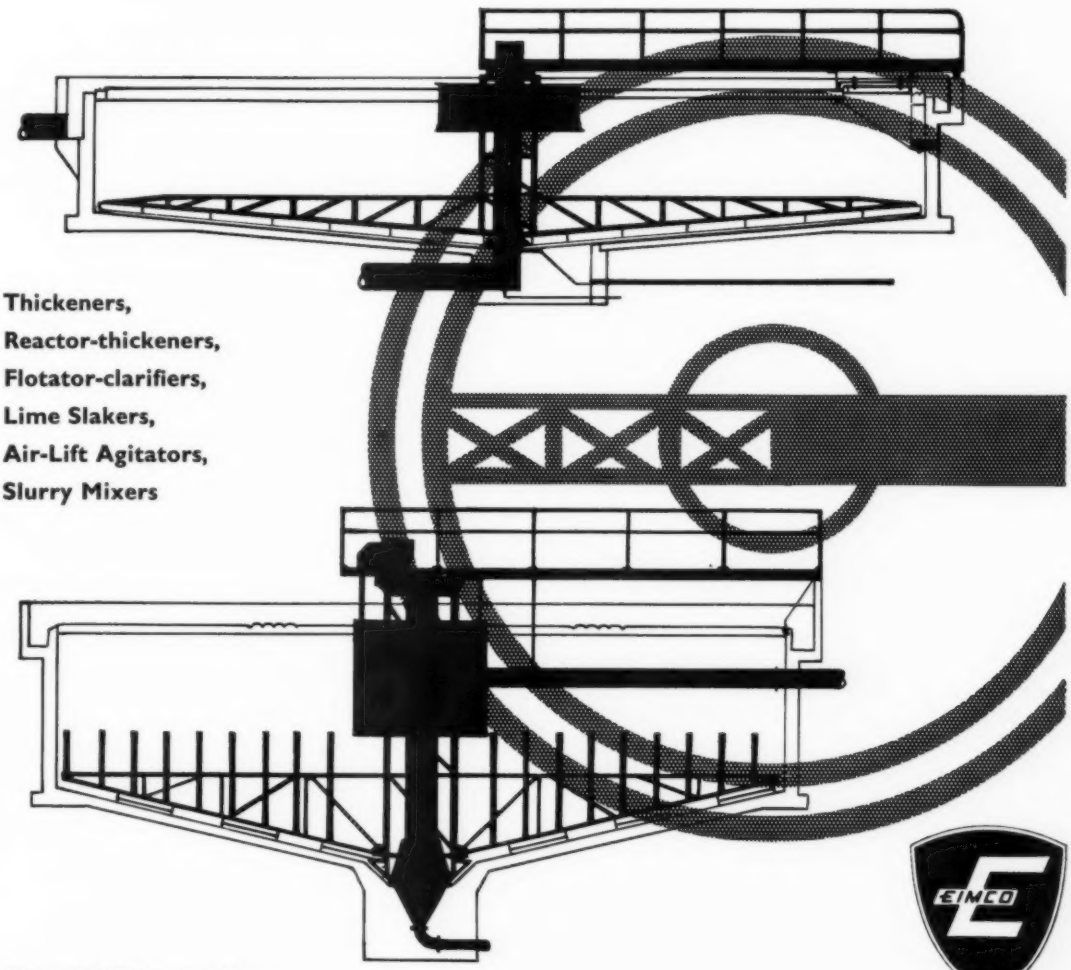

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P.2699

tray inefficiencies, arbitrary vapour-liquid equilibrium and time delays for liquid flow between the trays. The column trays are considered separately from the overhead and reboiler systems so that the effect of different overhead and boiler systems is easily established. The method makes possible the synthesis of a feed-forward control system which, from measured values of uncontrolled input variables, adjusts other controlling input variables in such a way always to maintain output variables at exactly their desired values.

From frequency response curves, representing the dynamic relations of the operating variables, the authors synthesize the transfer functions for an optimum feed-forward control system. The effectiveness of the system has been checked by simulating both the column and the control system on a general-purpose analogue computer.

*"A Theoretical Study of the Dynamics and Control of Binary Distillation," D. W. T. RIPPIN and D. E. LAMB, Dept of Chemical Engineering, University of Delaware, Newark, Delaware, U.S.A. (Presented to the December 1960 meeting of the A.I.Ch.E.)

Dimensioning Pipelines for X-12 or X-22 Refrigerating Plants

A NUMBER of charts useful for dimensioning pipelines in refrigerating systems operating on X-12 or X-22 refrigerant have been published recently by the Danfoss Company* of Denmark. Knowing the refrigeration load, the evaporating temperature in the evaporators, the length of pipeline, and the permissible pressure loss in the pipelines, suitable pipeline diameters can be selected. The diagrams are actually prepared for X-12 refrigerant. In the case of the liquid lines and delivery pipes, the dimensions are identical for X-22. In the case of the suction lines for X-22 a pipe diameter one size smaller than that determined from the diagrams should be used. Recommended limitations for the pressure losses in the lines are:

For the liquid lines: not exceeding 5 lb per sq. in.

For the delivery pipes: not exceeding 2 lb per sq. in.

For the suction lines: not exceeding 2-3 lb per sq. in. normally; for low temperature plants, not exceeding 0.5 lb per sq. in.

* The Danfoss Journal, No. 3, 1960, page 43.

Fluidized Steam-Iron Process for Hydrogen

AS part of a programme for improving processes that utilise coal or coal-derived materials, the U.S. Bureau of Mines has made a pilot plant study of producing hydrogen by the alternate oxidation and reduction of iron-iron oxide using the fluidized bed technique*. Compared with the fixed-bed steam-iron process, the iron-iron oxide solids are of much smaller particle size, and because their surface area is large, the reaction rate is faster per volume of catalyst. By feeding solids and gases countercurrently, improved conversion of the reactants is obtained. The fluidized system allows continuous operation with transport of the solids between the oxidiser and reducer, and is readily adaptable to high-pressure operation.

Among the optimum conditions for this process were, for the reduction stage, a temperature of 750°C, space velocity of producer gas—300 hr^{-1} (based on operation at 7 atm) and solids residence time—2-3 hours. For the oxidation step the optimum conditions included a temperature range of 600-800°C, a space velocity of steam, 350 hr^{-1} (based on operation at 7 atm) and a solids residence time of 30 minutes. The purity with CO_2 removal was 95-99 per cent.

To produce 1000 standard cu ft of hydrogen, about 3800 standard cu ft of producer gas with a hydrogen-plus-carbon monoxide concentration of 40 per cent, would be required and about 80-90 lb of steam, with 590 lb of oxidised solids. The spent producer gas, following reduction, provides waste heat steam and energy to drive turbocompressors. If the operations are carried out at 7 atm, sufficient energy is available for compressing air for the gas producers to 7 atm and the product hydrogen from 7 to 30 atm. The thermal efficiency of the process is about 55 per cent, compared with about 52 per cent for the gasification of coal with steam and oxidation followed by two stages of shift and CO_2 removal. At present, however, the fluidized-bed steam/iron process is more complex at a higher capital cost.

*J. H. FIELD, A. J. FORNEY, and S. J. GASIOR, Division of Solid Fuels Technology, Branch of Coal-to-Oil Research, Region V, Project 3451 (35), June 1960. Bureau of Mines, U.S. Dept. of the Interior, Pittsburgh, Pa.

A Course on Drying and the Theory of Heat and Mass Transfer

A COURSE of 10 weekly lectures on this subject is to be given by the National College for Heating, Ventilating, Refrigeration and Fan Engineering at the Borough Polytechnic, Borough Road, London, S.E.1. The course will commence on the 10th April at 6.30 p.m. and registration for the lectures requires application and payment of the modest fee of £1.

The course is to be conducted by Mr. E. WOODCOCK, M.Sc., lecturer in Heat Transfer at the National College. It will be suitable for those engaged in the design, specification, operation and manufacture of drying equipment and to those also with a general interest in heat and mass transfer.

DIARY

Institution of Chemical Engineers

February 28. *North Western Branch.* The Manufacture of Wet Phosphoric Acid. G. E. BOUGHEY. **7.30 p.m.** Birkenhead Technical College.

March 7. Symposium on Fluidization. **2.30 p.m.-7.30 p.m.** The Geological Society, Burlington House, London, W.1. (Registration required.)

March 8. *North Western Branch.* Chemical Engineering Aspects of the Underground Gasification of Coal. F. E. WARNER. **7 p.m.** Lecture Theatre A. Houldsworth School of Applied Science, Leeds.

Birmingham University Chemical Engineering Society

March 28. A Symposium: Computers for the Chemical Engineer. (In conjunction with S.G. section, I.Chem.E., Midlands Centre.) University of Birmingham, Birmingham 15.

The Institution of Civil Engineers

March 7. Joint Meeting with the Royal Institute of British Architects. "The Problem of Housing Large-Scale Plant," by W. S. ATKINS and HOWARD LOBB at **5.30 p.m.** at the Institution.

The Society of Instrument Technology

March 28. "Automatic Optimisation," by DR. P. E. W. GRENSTAD, Ph.D., M.A. and O. L. R. JACOBS, M.A., at **5 p.m.** Manson House, 26 Portland Place, London, W.1.

Society of Chemical Industry

March 16. *Newcastle-upon-Tyne Section.* Joint Meeting with Institution of Chemical Engineers. "Tonnage Oxygen Production," by DR. P. M. SCHUFTAN at **6.30 p.m.** Stephenson Building, King's College, Newcastle-upon-Tyne.

March 14. *Chemical Engineering Group.* "Production of Hydrogen from Oil," by H. G. KLINKERT at **6 p.m.** 14 Belgrave Square, London, S.W.1.

April 7. *Heavy Organic Chemicals Group.* "Present Trends of Developments in Chemicals from Petroleum in France," by MONS. P. A. LAURENT at **6 p.m.** 14 Belgrave Square, London, S.W.1.

BRITISH GROUP – AMERICAN ASSOCIATION OF COST ENGINEERS

THE British Group was formed at a small meeting attended by some 13 people on 14th July, 1960, in London. Since then it has developed into a full organisation providing a meeting ground, forum and channel of technical study and development for Cost Engineers, with the objective of furthering the application of scientific principles and techniques to problems of cost estimation, cost control and profitability.

Membership has multiplied and applications are coming forward at a steady rate. A well-attended first public meeting was held at the Institution of Civil Engineers on 12th December, 1960. At this meeting a technical paper was presented and discussed.

Technical committees have commenced work on Terminology, Cost Control, Cost Estimating, and Cost Indices. Further committees will deal with Operational Costs, Profitability and Education.

Organisational committees are working on Library, Publications and Publicity, Planning and Co-ordination of activities. A reference library and information service is available to members.

The Group was originally brought into being as a regional British Section of The American Association of Cost Engineers. All members are primarily individual members of the latter body. Since it has become necessary due to the numbers and interests of members now joining to provide the whole range of institutional services, it is proposed to change the Group's status in the near future to that of an independent (British) Association of Cost Engineers, though providing for full affiliation and interchange of facilities and data with the pioneer body in the U.S.A. This will enable the Group to accept members directly without requiring them to join A.A.C.E., and greatly extend its usefulness to British Industry and Cost Engineers everywhere.

The next public meeting, at which a technical paper will again be presented, will take place on March 10th at 5.30 or 6 p.m. at the Institution of Civil Engineers. The speaker is to be Mr. R. J. ANDERSON whose paper will deal with a number of important aspects of Air-Cooled Heat Exchangers including their economics.

Attention will be given to the evaluating of tenders for this kind of equipment and to "turnkey" contracts.

Anyone interested in the aims and objectives of the Association should contact the secretary, Mr. T. B. WOODS, c/o Humphreys and Glasgow Ltd., Carlisle Place, London, S.W.1, who will gladly answer enquiries and supply application forms for membership.

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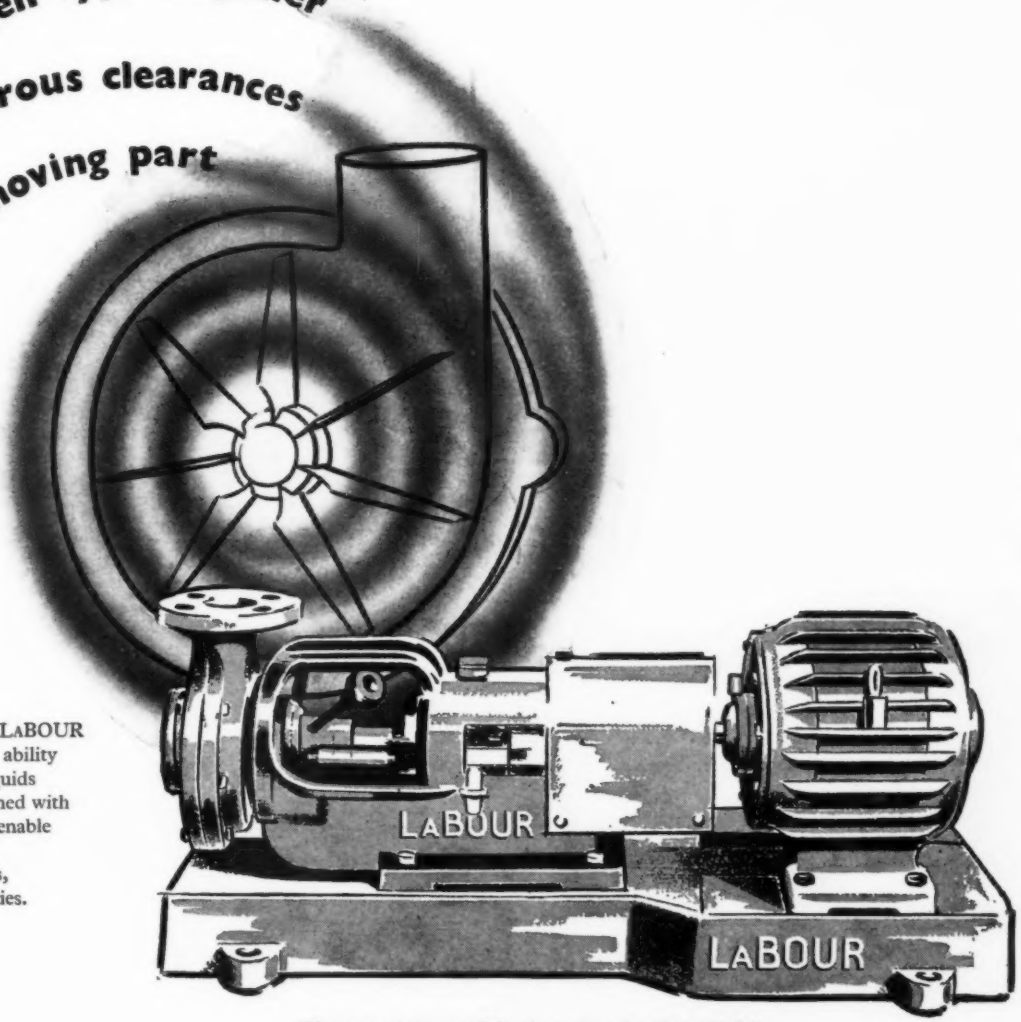

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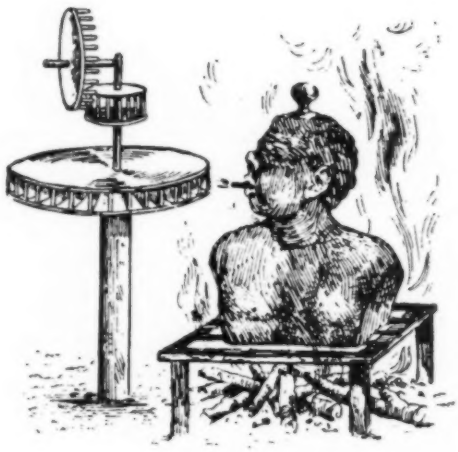

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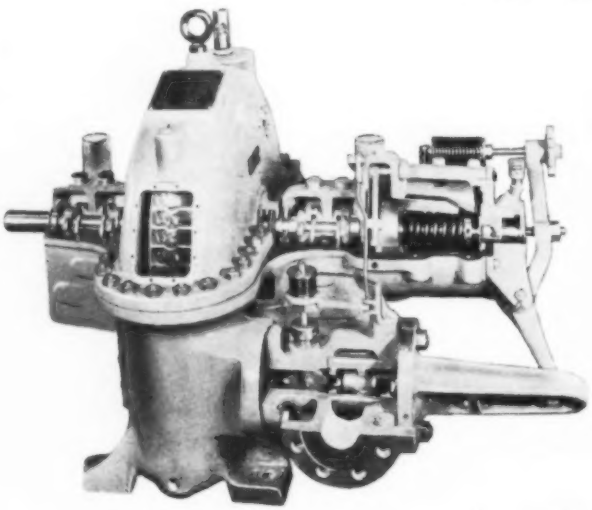

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British Chemical Engineering
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Instrumentation: Present and Future

A NUMBER of features of modern industry cause attention to be focused upon the techniques embraced by the term "instrumentation". In the first place, economic pressures arising within and discoveries and developments taking place outside industry tend to reduce the effectiveness of its established technological practices: countermeasures are seen in greater mechanisation and in an extended use of instrumentation. Again, the lengthy period which sometime elapses from the time a decision is taken to erect a manufacturing plant, to the actual emergence of its product in the desired quantity and quality, is a source of great expense, tying up, as it does, much capital and technical effort. A reason for delays of this kind has frequently been the failure to reveal the trouble spots early on in the life of a project, a contributory cause being the failure to study the control problems adequately at the design stage and therefore to miss an early opportunity for modifying either process or instrumentation.

The importance of such aspects of instrumentation merits a brief review of its present state and a look into the future.

How may one characterise modern instrumentation? In the first place, its equipment is highly reliable and can offer an ever-extending range of measurement for most of the variables commonly encountered in industry, and several composition measuring instruments have made their début. The production of small, accurate and responsive pneumatic transmitters and controllers employing the force balance principle has brought in its train a number of advantages such as the independence of controller and indicator, and the ability to mount the controller close to the correcting unit. Closely connected with this development is that well-established instrumental technique, the graphic panel, a striking example of the use of compact instruments; yet another method of displaying control information, the console panel represents, perhaps, the limit of compactness in this direction.

The appearance of instruments for composition and analysis, for example, the chromatograph; the widespread use of electro-pneumatic controllers and purely electronic instruments, data loggers, operator guide computers and computing control systems are other noteworthy signs of the times. Another outstanding feature of the present period, closely related to the problem of predicting controller performance, is the widespread effort to develop the theoretical side of control engineering. The many recent conferences that have been held in many countries are indicative of the attention being lavished upon this aspect of instrumentation.

And what of the future? In fields more detached from the process industries there are other techniques which could conceivably find application in those industries. The principles of fast response, pneumatic and hydraulic actuators, are well understood, although the equipment itself is more costly than the well-tried low-pressure pneumatic valve positioners so frequently encountered in the process field. Given economically sound applications, this kind of hardware may well find its way into the process field.

Sampled data techniques are also likely to have much to offer; one view of their possibilities is that they offer control actions that can exact process performance to a degree unobtainable with conventional tri-mode controllers. They also provide a link between sampling measurements and control by computer.

Much sound thought and a great deal of speculation have been given to this latter theme and it is well to recall some cautionary words on this subject. As L. S. YOXALL* has said, before the benefits of the computer can be realised to the full a great deal of accepted instrument practice needs close re-examination; for example, with the introduction of the computer absolute measurement errors acquire a new significance because human judgment, which can play an active role in conventional control schemes, is no longer in the picture when the computer takes command. Of measurements which will not be good enough in these circumstances, YOXALL mentions that of flow by orifice, which can be rendered inaccurate by adverse plant factors, and temperature by thermocouple, where the actual temperature at the thermocouple tip, which can be measured with high accuracy, may yet differ appreciably from the true temperature of a reacting gas mixture. And whatever the standard of computer design, problems, like those of the blocked impulse line, will still persist. They will need to be tackled at source and treated not as mundane details, but with an appreciation of their necessity to the success of a computer-controlled installation.

Apart from new techniques of measurement, such as instruments which will produce a single answer from the measurement of a number of variables, and the wider use of electronic instruments, the prospect of computer-controlled plants is certain to stimulate a greater study of the dynamics of plant and process.

* L. S. YOXALL: "Instrumentation, Past, Present and Future", Society of Instrument Technology, January 31, 1961.

66.048.375

THE GRAPHICAL DESIGN OF BUBBLE-CAP TRAYS

by
L. S. GYÖKHEGYI
and J. J. CZERMANN

The "equivalent diameter" concept and its application to the design of bubble-cay trays is described. By means of this concept, analysis of the bubble-cap tray sizing can be effected by means of three diagrams, while four other diagrams are available for carrying out the conventional hydraulic analysis rapidly. This series, consisting of seven diagrams in total, permits rapid determination of cap spacing

IN a previous paper[1] the importance of cap spacing was emphasised, based on the empirical rule established by ZENZ[2] that the annular area developed around the active caps and penetrated by bubbles should be twice as large as the slot area. Starting from this generally applied principle, it has become possible to give a new interpretation to the factor F, first used by DAVIES and applied universally since. It is important to recognise that the value of F cannot be fixed arbitrarily, since it is a function of cap spacing and other factors. The cap spacing has therefore been treated as a limiting factor of vapour/gas capacity, and it has been shown to be a function of cap diameter and slot length, as well as that of slot and crest width. Caps of various sizes must therefore be spaced at definite distances from each other in order to achieve total opening of the slots.

The equation defining the cap spacing is as follows:

$$a^2 - 1 = \frac{8 H_s X}{dc} \qquad \ldots . (1)$$

ZENZ's rule allows the "active" tray area to be determined by simple calculation, given the cap size and spacing, the vapour/gas quantity and the density of vapour/gas, as well as that of the liquid. The equation giving the "active" area for total opening of slots is:

$$A = \frac{2.207}{C} \frac{a^2}{a^2 - 1} V_m \sqrt{\frac{1}{H_s} \frac{\rho_G}{\rho_L}} \qquad \ldots . (2)$$

This Equation (2) reduces trial-and-error calculation for determining the tray cross-section and tray layout by one step, as compared with the application of the factor F. This is made possible by making use of the fact that in practice the slot area in distillation columns generally amounts to 60-70 per cent of the tray area, whereas in absorbers it is 45-55 per cent. Naturally, the determination of the slot area by equations is not the ultimate step in tray layout determination, but it has been used for the basis of the considerations published in this paper. Here it must be emphasised that the proposals of this article, as in the previous paper, assume that the annular area developed round active caps and penetrated by bubbles is twice the slot area.

As was shown by DAVIES,[3] and later by BOLLES,[4] the bubble-cap tray layout must take into account several factors, in particular the hydraulic factors. The more important characteristics, according to DAVIES, are as follows: (a) downflow residence time; (b) vapour distribution ratio; (c) vapour pressure drop; (d) free height in downflow; (e) minimum and maximum superficial slot velocities.

Recommended values are also published by DAVIES covering the above five items.

Apart from these important items, the design must provide enough disengaging area between the outside cap row and the weir, and ensure that the caps placed on the tray perimeter are not too close to the column wall. Thus it often happens, even if the five most important characteristics given by DAVIES are taken into consideration, that new tray layout must be designed in order to provide sufficient disengaging area and reduce end wastage.

It is therefore necessary to carry out the calculation using realistic assumed values at the beginning of each part of the calculation. The correctness of the assumed values is then either proved or disproved by the results. In the latter case, the calculation must be repeated with other assumed values. The trial-and-error steps might be considerably reduced if a correlation were available for the determining of tray cross-section and layout, which would take into account both the vapour/gas *and* liquid load equally. Such correlation, similar to the BAIN-HOUGEN Equation (5) applied to the determination of packed column diameters, has, however, not yet been developed.

ZENZ has attempted to meet this need by developing a method based upon experiments carried out by KIRSCHBAUM. In his experiments, KIRSCHBAUM concluded that:

$$\frac{A_C}{A_T} + 2 \frac{A_L}{A_T} \cong \text{constant}$$

This, however, has not been proved in practice. The deviations are especially large when the bubble-cap trays operate under vacua or as absorbers.

It seems that a general easy-to-handle correlation is not an immediate possibility—one which, at the same time, can render unnecessary *all* trial-and-error calculations of bubble-cap column design. Therefore, it would be valuable to develop a method which reduces the trial-and-error steps considerably—the purpose of this paper.

L. S. GYÖKHEGYI and J. J. CZERMANN are chemical engineers at the Hungarian Chemical Plant Design and Engineering Institute, Budapest.

Symbols Used

a = ratio of cap pitch to cap diameter;
A = "active" area per tray, sq. ft;
A' = disengaging area + end wastage per tray, sq. ft;
A_c = outside capped area per tray, sq. ft;
A_e = inside capped area per tray, sq. ft;
A_L = downcomer area (per side), sq. ft;
A_m = smaller of the areas: annular or reversal area per tray, sq. ft;
A_R = inside riser area per tray, sq. ft;
A_T = tray cross-sectional area, sq. ft;
b = mean width of tray $\left(\frac{D_T + W}{2}\right)$ ft;
B = cap characteristic constant $(6C)(a^2 - 1)(\sqrt{H_S})$;
C = coefficient in maximum slot capacity formula;
C_d = hydraulic gradient factor;
$d_o = H_S + h_{st} + h_{ow} + S$, in.;
d_c = outside cap diameter, in.;
d_R = inside riser diameter, in.;
D = equivalent diameter of A, ft;
D' = equivalent diameter of A', ft;
D_c = equivalent diameter of A_c, ft;
D_L = equivalent diameter of A_L, ft;
D_T = tray diameter, ft;
f = function in Equations (23), (24a) and (54a);
h = maximum pressure drop through riser, cap and slots on wet tray, in. of clear liquid;
h_a = pressure drop through the cap on wet tray, in. of clear liquid;
h'_a = pressure drop through the cap on dry tray, in. of water;
h_{ow} = height of liquid crest, in.;
h_R = pressure drop through the riser on wet tray, in. of clear liquid;
h'_R = pressure drop through the riser on dry tray, in. of water;
h_S = slot opening, in.;
H_S = slot height, in.;
h_{st} = static submergence, in.;
h_t = total gas/vapour pressure drop per tray, in. of clear liquid;
h_w = weir height $(S + H_S + h_{st})$, in.;
l_1 = total free space between caps normal to liquid flow, average of various rows, in.;
l_2 = total free space between risers normal to liquid flow, average of various rows, in.;
L_m = maximum liquid lead for tray, cu. ft./sec.;
$m = A_c/A'$;
n = number of caps in any row;
N_1 = calculated number of caps;
N_2 = number of caps resulting from the tray layout;
P = flow parameter;
r = number of rows of caps;
s = skirt clearance opening, in.;
S = height of skirt clearance, in.;
t = liquid residence time in downflow, sec.;
T = tray spacing, in.;
v = liquid velocity in downflow, in./sec.;
V_m = maximum vapour/gas load for tray, cu. ft/sec.;
V_2 = vapour/gas load sufficient for the total opening of N_2 number of caps, cu. ft/sec.;
$V'_2 = V_m - V_2$, cu. ft/sec.;
W ft = length of weir, ft;
X = ratio of the sum of slot width to cap perimeter;
$\alpha = l_2/l_1$;
$\triangle$ = hydraulic gradient, in.;
$\triangle_{11}$ = hydraulic gradient, in inches, if $V_m/A_T\sqrt{\rho_G} = 1.1$;
ρ_G = vapour/gas density, lb/cu. ft;
ρ_L = clear liquid density, lb/cu. ft.

Simple Assumptions — Simple Correlations

To develop the method reducing the trial-and-error steps considerably, further assumptions must be made in addition to those affecting the validity of Equations (1) and (2) which were:

(1) total opening of the slots of ring-shaped caps is brought about by maximum vapour/gas rate;
(2) equilateral triangular cap pitch;
(3) flow of liquid on the tray is cross flow;
(4) liquid velocity in the overflow: maximum 2 in./sec.;
(5) residence time of liquid in the overflow: minimum 5 sec.

These assumptions are conventional and do not involve any new conceptions. In connection with condition (5), this means the fulfilment, at the beginning of design work, of the assumption considered the most important by DAVIES. According to Equation (2):

$$A_c = \frac{2}{C(a^2 - 1)} V_m \sqrt{\frac{1}{H_S}\frac{\rho_G}{\rho_L}} \qquad \ldots.(3)$$

As from the conventional definition of liquid residence time, the necessary downcomer area on one side of the tray will be:

$$A_L = \frac{12\,L_m}{T}\,t \qquad \ldots.(4)$$

From condition (4), however:

$$V = \frac{T}{t} = 2 = \frac{12\,L_m}{A_L}$$

Hence

$$\boxed{A_L = 6\,L_m} \qquad \ldots.(5)$$

Dividing Equation (3) by Equation (4):

$$\frac{A_c}{A_L} = \frac{1}{6}\frac{T}{t}\frac{1}{C(a^2 - 1)\sqrt{H_S}}\frac{V_m}{L_m}\sqrt{\frac{\rho_G}{\rho_L}} \qquad \ldots.(6)$$

The constants of this equation may be grouped thus:

$$\boxed{6\,C(a^2 - 1)\sqrt{H_S} = B} \qquad \ldots.(7)$$

According to this expression, not only different a values, but also different B values correspond to each cap sizing.

Writing

$$\boxed{\frac{L_m}{V_m}\sqrt{\frac{\rho_L}{\rho_G}} = P} \qquad \ldots.(8)$$

allows Equation (6) to be simplified $\left(\frac{T}{t} = 2\right)$ as follows:

$$\boxed{\frac{A_c}{A_L} = \frac{2}{PB}} \qquad \ldots.(9)$$

Equation (8) may also be reduced to:

$$\boxed{A_c = \frac{12}{B}\,Vm\sqrt{\frac{\rho_G}{\rho_L}}} \qquad \ldots.(10)$$

Similarly, Equation (2) may be written as:

$$\boxed{A = A_c\frac{a^2}{0.906}\,Vm\sqrt{\frac{\rho_G}{\rho_L}}} \qquad \ldots.(11)$$

Equivalent Diameter Defined

Any bubble-cap tray, whether in an absorber or in a rectifier, has the following areas:

$$A_T = A + 2A_L + A' \qquad \ldots.(12)$$

The designer may assume arbitrarily that the active area, the downcomer area and the disengaging area + end wastage

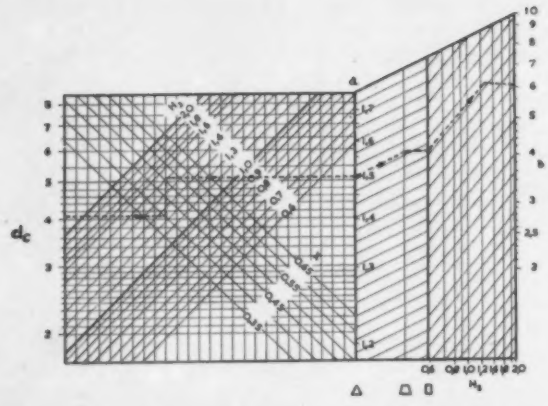

Fig. 1. Chart for determining cap pitch to diameter ratio and cap constant B *for caps of various dimensions.*

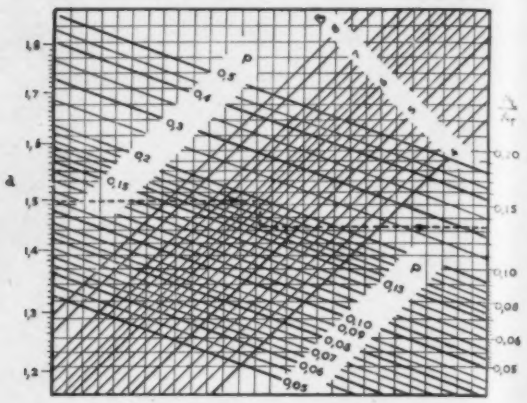

Fig. 2. Graphical determination of the ratio area of downcomer to tray cross-sectional area.

area are circles with the diameters, D, D_L and D' respectively. The assumption concerning the allocated area applies, of course, to the capped area also, which may be substituted by a circle with the diameter D_c. According to this:

$$D = \sqrt{\frac{A}{0.785}} \qquad D' = \sqrt{\frac{A'}{0.785}}$$

$$D_c = \sqrt{\frac{A_c}{0.785}} \qquad D_L = \sqrt{\frac{A_L}{0.785}}$$

The diameters of these circles are the so-called "equivalent diameters".

The introduction of the notion of "equivalent diameter", together with the validity of Equation (1) to (11), means a new outlook for the bubble-cap tray specialist. The undernoted simple empirical correlation has been developed from a great many tray layouts on an industrial scale, designed on the basis of Equations (1) to (11):

$$\boxed{D \cong D_c + D'} \qquad \ldots.(14)$$

Equation (14) is approximately true for a vacuum still $\left(\frac{A_L}{A_T} \simeq 5\%\right)$ or an absorber $\left(\frac{A_L}{A_T} \simeq 20\%\right)$.

Tray Diameter from Equivalent Diameter

Taking the square of Equation (14), the following equation is obtained:

$$A_c + 2\sqrt{A_c A'} + A = A' = A_c \frac{a^2}{0.906} \qquad \ldots(15)$$

or

$$A_c\left[\frac{a^2}{0.906} - 1\right] - A' = 2\sqrt{A_c A'} \qquad \ldots.(16)$$

Squaring Equation (16) gives:

$$A_c^2\left[\frac{a^2}{0.906} - 1\right]^2 - 2A_c A'\left[\frac{a^2}{0.906} - 1\right] + A'^2 = 4A_c A' \qquad \ldots.(17)$$

Rearranging the equation:

$$A_c^2\left[\frac{a^2}{0.906} - 1\right]^2 - 2A_c A'\left\{\left[\frac{a^2}{0.906} - 1\right] + 2\right\} + A'^2 = 0 \qquad \ldots.(18)$$

Dividing Equation (18) by A'^2 we obtain:

$$\frac{A_c^2}{A'^2}\left[\frac{a^2}{0.906} - 1\right]^2 - 2\frac{A_c}{A'}\left[\frac{a^2}{0.906} + 1\right] + 1 = 0 \quad \ldots.(19)$$

According to Equation (19), $\frac{A_c}{A'}$ is a direct function of a only, and an indirect function therefore of the cap sizing, if the accuracy ensured by Equation (14) is found satisfactory. From Equation (19):

$$\frac{A_c}{A'} = \frac{\frac{a^2}{0.906} + 2\sqrt{\frac{a^2}{0.906}} + 1}{\left[\frac{a^2}{0.906} - 1\right]^2} = m \qquad \ldots.(20)$$

From Equation (20), Equation (12) gives:

$$A_T = A_c\frac{a^2}{0.906} + 2A_L + \frac{A_c}{m} = A_c\left[\frac{a^2}{0.906} + \frac{1}{m}\right] + 2A_L \qquad \ldots.(21)$$

Dividing both sides of the equation by A_L:

$$\frac{A_T}{A_L} = \frac{A_c}{A_L}\left[\frac{a^2}{0.906} + \frac{1}{m}\right] + 2 \qquad \ldots.(22)$$

Substituting Equation (9) into Equation (22), we obtain:

$$\boxed{\frac{A_T}{A_L} = 2\left\{\frac{1}{PB}\left[\frac{a^2}{0.906} + \frac{1}{m}\right] + 1\right\}} \qquad \ldots.(23)$$

The expression in square brackets in this equation is a function of a only, i.e. indirectly a function of the cap sizing, similarly to B. Besides the above-mentioned terms, the equation contains only factor P, defined by Equation (8). As a consequence of the foregoing, and since A_L is a function of the liquid quantity, the implicit form of Equation (23) will be:

$$A_T = f[V_m, L_m, \rho_G, \rho_L, d_c, H_S, X, C] \qquad \ldots.(23a)$$

Equation (23) represents a correlation which, similar to the above-mentioned BAIN-HOUGEN equation, takes into account, besides the quantities and densities of vapour/gas and liquid, also the cap sizing for the determination of bubble-cap tray cross-sections. By creating this analogy, a new method has been developed for the determination of the cross-section of tray columns. This method was predicted by SCHUMACHER[7] some years ago, and it was he who

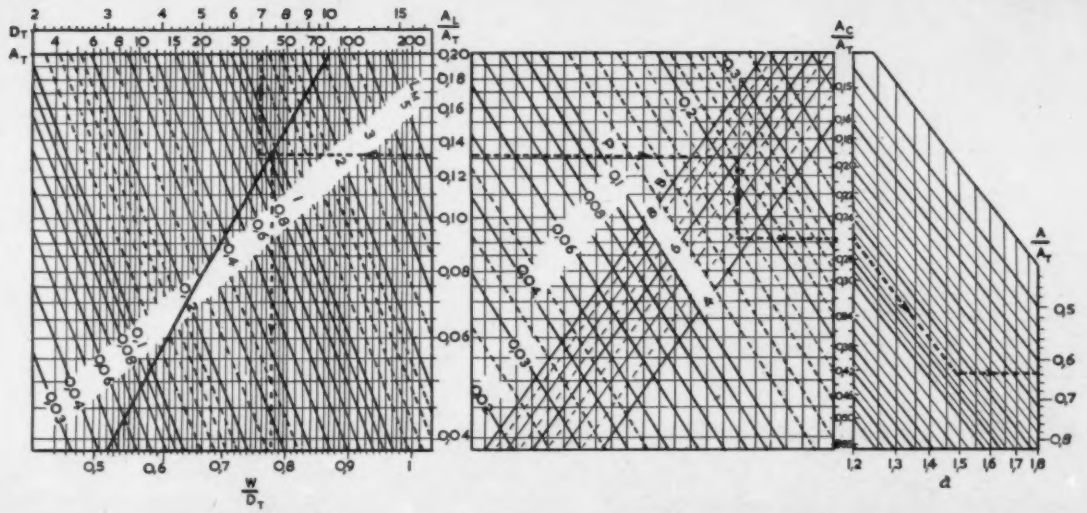

Fig. 3. Graphical determination of the ratio of cap outer and interior areas and of "active" area to tray cross-sectional area.

made the first steps towards its development.

No difference is made in this method between the trays of absorbers and those of fractionators, just as there is no difference in principle for the sizing of packed columns.

On the basis of Equation (9) and of the following correlation

$$\frac{A_c}{A'} = m$$

the undernoted equation may easily be derived

$$\frac{A'}{A_T} = \frac{A_L}{A_T}\frac{2}{PB}\frac{1}{m} \qquad \ldots.(24)$$

Upon determination of the value of $\frac{A_C}{A_T}$ by Equation (23), the value of $\frac{A'}{A_T}$ can also be calculated easily, with introducing further variables, by means of Equation (24). Since among the factors shown in Equation (24) A_L is a function of the liquid quantity only, B and m that of the cap spacing only, the implicit form of Equation (24) will be:

$$A' = f(V_m, \rho_G, \rho_L, d_c, H_S, X, C) \qquad \ldots.(24a)$$

The importance of the fact that the disengaging area + end wastage area is independent of the liquid quantity must be noted here, and will be referred to later.

The Next Step: The Influence of Pressure Drop

The new correlations submitted in the foregoing result in a considerable saving of time and work when calculating tray cross-sections and tray layouts. For the designer it is, however, clear that the correctness of tray layout must be controlled by the determination of pressure drop.

Pressure drop on a tray consists of the following components:

I. Resistance of flues, caps and slots.
II. Height of liquid overflowing the weir.
III. Hydraulic gradient.
IV. Pressure drop in overflow tube.

From the enumerated items I-IV, item I represents the resistance of the structural elements placed in the way of the uprising vapour/gas transport, whereas items II-IV are the results of liquid flow. For the sake of completeness, apart from the theory of equivalent diameters, full details are given of the correlations by means of which the total pressure drop on the tray may be determined. In any correlations, where it was necessary and feasible, the constants a and B, characteristic for caps of various dimensions, have been used.

Determination of the Pressure Drop of the Tray

I. Resistance of Flues, Caps and Slots

In the previous paper cited, the cap spacing has been shown as a limiting factor of the vapour/gas capacity. On the basis of this principle, the pressure drop caused by the vapour/gas flow in the flues and caps can be expressed as a function of the cap spacing if the maximum vapour/gas quantity fully opens the slots.

To introduce these conditions, the formulæ published by DAUPHINE[5] have been utilised. The so-called "dry" pressure drop (no liquid on the tray) of the riser, taking the most frequent case, i.e., if the reversal area is equal to or larger than the riser area, amounts to

$$h'_R = 1.7810^{-3} d_R \left(\sqrt{\rho_G}\,\frac{V_m}{A_R}\right)^{2.09} \qquad \ldots.(25)$$

As in the previous paper, the following simplifications have been introduced according to BOLLES:

$$d_R = 0.7 d_c \text{ and}$$
$$A_R = 0.49 A_c \qquad \ldots.(26)$$

Therefore, Equation (25) can be modified as follows:

$$h'_R = 1.7810^{-3} 0.7 d_c \left(\sqrt{\rho_G}\,\frac{V_m}{0.49 A_c}\right)^{2.09} \qquad \ldots.(27)$$

According to Equation (10), however:

$$\frac{V_m}{A_c}\sqrt{\rho_G} = \frac{B}{12}\sqrt{\rho_L}$$

hence

$$h'_R = 3.0510^{-5} d_c B^{2.09} \rho_L^{1.045} \qquad \ldots.(28)$$

"Wet" pressure drop of the riser, when the liquid reaches the upper edge of the slot, will be

$$h_R = h'_R \frac{62.4}{\rho_L} = 1.90\,10^{-3} d_c B^{2.09} \rho_L^{0.045} \quad \ldots.(29)$$

"Dry" pressure drop of the cap (annular area + reversal area) is:

$$h'_a = 1.09\,10^{-2} \left(\sqrt{\rho_G} \frac{V_m 2 A_R^2}{A_R A_m A_e} \right)^{1.71} \quad \ldots.(30)$$

The calculation of the cross-sections shown in Equation (30) is somewhat lengthy. For the sake of facilitating the calculation, within a small margin of error, the following approximations have been made:

$$A_m \simeq A_R \text{ and}$$
$$A_e \simeq A_c$$

Equation (30) will then assume the new form of:

$$h'_a = 1.09\,10^{-2} \left(\sqrt{\rho_G} \frac{2\,Vm}{A_c} \right)^{1.71} \quad \ldots.(31)$$

Combining Equation (10) with Equation (31), we have

$$h'_a = 5.06\,10^{-4} B^{1.71} \rho_L^{0.855} \quad \ldots.(32)$$

The "wet" pressure drop of the cap:

$$h_a = h'_a \frac{62.4}{\rho_L} = 3.16\,10^{-2} B^{1.71} \rho_L^{-0.145} \quad \ldots.(33)$$

For accurate results, the deviations caused by the above approximations may be compensated by multiplying Equation (33) by a numerical constant. The value of this constant depends on the magnitude of the deviations between A_m and A_R, as well as those between A_e and A_c.

Since in the case of maximum vapour/gas load, according to the original assumption, the slots are totally opened, the total "wet" pressure drop resulting from the maximum vapour/gas quantity flowing over the tray will be:

$$h = h_R + h_a + H_S \quad \ldots.(34)$$

The calculated number of caps and that obtained by the design of tray layout is, in general, not quite in agreement. Since the calculated number of caps corresponds to the maximum estimated vapour/gas quantity, the results obtained from Equations (29) and (33) must be modified in accordance with the number of caps resulting from the tray layout. The modification will be carried out by multiplying h_R by $\left(\frac{N_1}{N_2}\right)^{2.09}$, and the value of h_a by $\left(\frac{N_1}{N_2}\right)^{1.71}$.

It is a different matter with the "wet" resistance of the slots, which is equal to the length of the open slots. There are two possibilities only here, viz.

1. If $\frac{N_1}{N_2}$ is smaller than 1, the slots are not opened totally, but only to the length of h_s. The open length of the slot depends not only on the ratio $\frac{N_1}{N_2}$, but also on the shape of the slot. Taking an oblong slot, the correlation between the open and the full length of the slot, as well as the ratio $\frac{N_1}{N_2}$, will be:

$$\frac{N_1}{N_2} = \left[\frac{h_S}{H_S}\right]^{3/2} \quad \ldots.(35)$$

The same with triangular slots:

$$\frac{N_1}{N_2} = \left[\frac{h_S}{H_S}\right]^{5/2} \quad \ldots.(36)$$

With trapezoidal slots:

$$\frac{N_1}{N_2} = 0.714 \left[\frac{h_S}{H_S}\right]^{3/2} + 0.286 \left[\frac{h_S}{H_S}\right]^{5/2} \quad \ldots.(37)$$

Knowing N_1, N_2 and H_s from Equation (36) and (37), the value of h_s is easily obtained.

2. If $\frac{N_1}{N_2}$ is larger than 1, the slots are totally open, and vapour or gas leaves through the skirt clearance also.

The vapour/gas quantity opening the skirt clearance of S length of N_2 caps to the length of s in the case of $\frac{N_1}{N_2} > 1$ will be:

$$V'_2 = 0.79 \frac{N_2 d_c \pi S}{S\,144} \sqrt{\frac{\rho_L}{\rho_G}} s^{3/2} = 0.79 \frac{N_2 d_c \pi}{144} \sqrt{\frac{\rho_L}{\rho_G}} s^{3/2} \quad \ldots.(38)$$

The basis of this equation is the assumption of HUITT and HUNTINGTON,[9] which is that the skirt clearance area of a cap is equal to a rectangular slot area of width equal to the cap circumference, and the length of S. By means of this assumption, the value of V'_2 can be expressed by the formula which holds good for oblong slots, of ROGERS and THIELE,[10] as shown in Equation (38).

Again, according to ROGERS and THIELE, the vapour/gas quantity required for the total opening of the slots of N_2 caps will be:

$$V_2 = C \frac{N_2 d_c \pi H_S X}{144} \sqrt{\frac{H_S \rho_L}{\rho_L}} \quad \ldots.(39)$$

Clearly, from the above notation, the total vapour/gas quantity flowing through N_2 caps is:

$$V_m = V_2 + V'_2 \quad \ldots.(40)$$

It is further clear that V'_2, the quantity leaving through the skirt clearance, is proportional to the difference N_1-N_2. Therefore, dividing Equation (38) by Equation (39), the following result will be obtained:

$$\frac{V'_2}{V_2} = \frac{V_m - V_2}{V_2} = \frac{N_1 - N_2}{N_2} = \frac{N_1}{N_2} - 1 = \frac{0.79}{CX} \left[\frac{s}{H_S}\right]^{3/2} \quad \ldots.(41)$$

Since the values C, X and H_S for the cap employed, as well as the values of N_1 and N_2, are known, the value of s may be calculated from Equation (41). The value of C shown in Equations (39) and (41) is:

Slot Shape	
Rectangular	0.79
Triangular	0.63
Trapezoidal	0.74

If, therefore, $N_1 \neq N_2$, then in case of $\frac{N_1}{N_2} < 1$:

$$h = h_R \left(\frac{N_1}{N_2}\right)^{2.09} + h_a \left(\frac{N_1}{N_2}\right)^{1.71} + h_S \quad \ldots.(42)$$

and in case of $\frac{N_1}{N_2} > 1$:

$$h = h_R \left(\frac{N_1}{N_2}\right)^{2.09} + h_a \left(\frac{N_1}{N_2}\right)^{1.71} + H_S + s \quad \ldots.(43)$$

II. Height of the Liquid Flowing over the Weir

Generally, the FRANCIS formula is used for the determination of the height of weir crest. This formula has been modified to express the dimension of the liquid quantity shown in cu. ft/sec. and, according to general practice,

the wall effect recommended by KIRKBRIDE[11] has been neglected. For the determination of the height of weir crest in case of a straight weir, Equation 44 may be used.

$$h_{OW} = 5.33 \left(\frac{L_m}{W}\right)^{\frac{2}{3}} \quad \ldots.(44)$$

III. The Hydraulic Gradient

Calculation of the hydraulic gradient is mostly effected by means of the DAVIES method. This method was improved by BOLLES, and an excellent analysis of the method was given in his above-cited comprehensive paper. BOLLES expressed the original correlation as a function of cap spacing, and also published a series of diagrams showing the equation as a function of the cap spacing and the skirt clearance. Methods were developed by ZENZ[13] and RODRIGUEZ[14] for the graphical representation of the hydraulic gradient established by DAVIES.

Application of the graphic method devised by BOLLES is somewhat limited with the method described in this paper, since no diagrams were published by BOLLES for cap spacing with a values larger than 1.5. It must be mentioned also, that when using the BOLLES diagrams, although this may be carried out quickly when applying the graphic method, assumed values of the hydraulic gradient must be applied, and these assumed values must later be controlled by the diagrams. This fact would involve more trial-and-error calculation, the number of which should be decreased rather by the designer and not increased. ZENZ's method does not consider the cap spacing, and the diagram established by RODRIGUEZ seems to be somewhat cumbersome.

In order to avoid these disadvantages, the DAVIES equation has again been taken as a starting point in the present paper:

$$\triangle_{1\cdot1}^{\frac{1}{2}}\{\triangle_{1\cdot1}(1.5r - 1.4) + 3r[h_w + h_{ow} + S(\alpha - 1)]\} = 450\, L_m\, r^{3/2}/2.15\, C_d\, l_1 \quad \ldots.(45)$$

The above form of Equation (45) differs from that generally used in the literature only by the fact that the dimension of L_m is cu. ft/sec., as has been mentioned before.

Factor C_d of Equation (45) is a function of the liquid load per foot mean tray width. The mean tray width is generally taken as the arithmetic means of the length of the chord measured at the last cap length, and the tray diameter. For the sake of simplicity, however, the ratio $D_T + W/2$ has been considered the mean tray width in this paper. For further simplification, both sides of Equation (45) have been divided by $\frac{3}{2}r$, and the value of the term $\frac{1.4}{r}$, being rather slight, has been neglected, since the deviation involved is small. If the mean tray width normal to flow is $h = D_T + W/2$ and the number of caps in one row on the length of b is n, then:

$$h = \frac{n\,d_c + n\,d_c\,(a-1)}{12} = \frac{n\,d_c\,a}{12} \quad \ldots.(46)$$

the value of l_1 amounts to

$$l_1 = n\,d_c(a-1) \quad \ldots.(47)$$

From Equations (46) and (47):

$$\frac{l_1}{h} = \frac{2l_1}{D_T + W} = \frac{12\,n\,d_c\,(a-1)}{n\,d_c\,a} = 12\,\frac{a-1}{a} \quad \ldots.(48)$$

Rearranging Equation (48):

$$l_1 = 6\,(D_T + W)\,\frac{a-1}{a} \quad \ldots.(49)$$

All the factors represented in Equation (49) are known from the previous calculations. It is, therefore, not even necessary to measure the length of the individual cap rows in turn on the drafted tray layout. With the same object, the meaning of the term $(\alpha - 1)$ on the left side of Equation (45) should be investigated. Since $\alpha = l_1/l_2$, it is advisable to express the value of α similar to Equation (49).

Obviously:

$$l_2 = n[ad_c - d_R] \quad \ldots.(50)$$

Applying the reduction introduced in Equation (26) here again, we have:

$$l_2 = n\,d_c(a - 0.7) \quad \ldots.(51)$$

The ratio of Equations (51) and (47) is

$$\alpha = \frac{a - 0.7}{a - 1} \quad \ldots.(52)$$

Hence:

$$\alpha - 1 = \frac{0.3}{a - 1} \quad \ldots.(53)$$

Substituting the above into Equation (45) gives the following equation:

$$\triangle_{1\cdot1}^{\frac{1}{2}}\left\{\triangle_{1\cdot1} + 2\left(h_W + h_{OW} + \frac{0.3S}{a-1}\right)\right\} = 23.3\,\frac{L_m}{D_T + W}\,\frac{r^{\frac{1}{2}}}{C_d}\,\frac{a}{(a-1)} \quad \ldots.(54)$$

Of the factors shown in Equation (54), the number of the cap rows must be read from the tray layout. The weir height is presented by the sum of the total slot length and the static submergence applied, whereas the skirt clearance is known by the utilisation of a cap of given sizing. Apart from factor C_d, all the other values are available from previous calculations for the determination of $\triangle$. It is to be mentioned in connection with factor C_d that it is the function of the ratio $\frac{L_m}{D_T + W}$; this function has been given by DAVIES graphically.

The hydraulic gradient calculated in this manner must be corrected according to DAVIES, since the value to be obtained from Equations (45) or (54) is correct only if $\frac{V_m}{A_T}\sqrt{\rho_G} = 1.1$. If this is not the case, a correction should be carried out by means of the Davies diagram. According to the above, the implicit form of the function of hydraulic gradient is:

$$\triangle_{1\cdot1} = f\left(\frac{L_m}{D_T + W},\, h_W,\, h_{OW},\, S,\, r,\, a\right) \quad \ldots.(54a)$$

IV. Pressure Drop in the Overflow Tube

The pressure drop resulting from the flow of the liquid in the overflow tube and from leaving it may be calculated by means of reliable correlations. In the opinion of the authors of the present paper, however, this pressure drop need not be taken into consideration when using the safe dimensioning practice recommended in this method, and it has therefore been neglected. As regards the downflow seal, recommended values have been published by DAVIES and BOLLES.

V. The Total Pressure Drop on the Tray can be Obtained from the Following Correlation:

$$h_t = h + h_{st} + h_{ow} + \tfrac{1}{2}\triangle$$

The values of the static submergence range from 0 to 1.5 in., depending on the operating pressures. See in this connection the work carried out by DAVIES.[3] It is a generally accepted rule in the practice that the height of the liquid column formed due to the pressure drop in the downcomer area should be at a maximum half of the tray distance, i.e.;

$$\frac{T}{h_t} \geqq 2$$

Tray Layout by Means of Equations (1) to (24). Sizing Analysis

First of all, the viewpoints to be followed when compiling the *starting data* will be summarised.

When carrying out a technical design, the designer will primarily fix those average values, which can be expected under normal operating conditions. Obviously, however, beyond these average values the maximum values must also be estimated, which depend on the variations of the system, since the capacity of distillation columns and absorbers should be dimensioned corresponding to these maximum quantities. Estimating these maxima is not an easy task, and the experience of the designer comes in here as a very important feature. The nature of the technique, the accuracy of data, the extent of the automatic control, etc., cannot be taken into account numerically, but they represent important factors for the estimation. An estimation always involves some inaccuracy. This, however, is still less dangerous than the danger of not taking into consideration any maxima. The same deliberations apply to the density variations of the vapour/gas and the liquid also. The value P of Equation (8) must therefore represent the maxima.

Upon fixing the flow parameter, P, a cap of any sizing is selected. From the cap sizing, the cap spacing is calculated by means of Equation (1), and the value B, characteristic for the cap, is obtained from Equation (7). The value of m is still required, and this may be calculated from Equation (20). Thereupon, all the data are known for the determination of the value of $\frac{A_L}{A_T}$.

From the value of $\frac{A_L}{A_T}$, the value of A_T and that of the complementary value of D_T is easily obtained by means of Equation (5). The value of the quotient $\frac{A_L}{A_T}$ and Equation (9) directly give the value of $\frac{A_c}{A_T}$, and indirectly that of A_c. From the value of A_c thus obtained, the calculated number of caps will be:

$$N_1 = 183.4 \frac{A_c}{{d_c}^2}$$

Multiplying the value of A_c by $\frac{a^2}{0.906}$, the value A is derived. From the values of A_T, A_L and A thus obtained, the value of A' is easily calculated according to Equation (12).

The steps enumerated above provide all the necessary data for tray layout.

Checking Tray Layout by Equations (25) to (44). Hydraulic Analysis

The layout design must, however, be controlled as to whether it meets the important requirements detailed at the beginning of this paper, specified by DAVIES. The first of these conditions is the claim that the downflow residence time of clear liquid should be at a minimum of 5 sec. Since this condition forms one of the fundamental assumptions of the present method, it need not be checked when the method is applied.

Another fundamental assumption of the present method is the condition that the quantity of vapour/gas is just enough for the total opening of the slots. As a consequence of this, the fulfilment of the last condition enumerated by DAVIES, i.e., the one about the minimum and maximum superficial slot velocities, also need not be controlled in connection with tray layout either.

The only values to be checked, given in the sequence of DAVIES, are:

The vapour distribution ratio;
The vapour pressure drop; and
The free height in downflow.

In the course of checking, the values of h_R and h_a must be calculated first on the basis of Equation (29), then from Equation (33). Thereupon, the check of the open slot length is carried out, depending upon whether the calculated or designed cap number is the larger one. If $N_2 > N_1$, the open length of the slot must first be determined from Equations (35) to (37), and afterwards the "wet" pressure drop of the tray calculated on the basis of Equation (42). If, however, $N_1 > N_2$, the "wet" pressure drop value is obtained by the solutions of Equations (41) and (43).

To obtain the numerical value of vapour distribution, the height of weir crest must first be calculated from Equation (44), and thereupon the weir height must be selected so as to allow for suitable static submergence between the upper edges of the slots and the weir level. All the data are now available for the solution of Equation (54) and for the correction of the hydraulic gradient obtained from it, as has been described in connection with Equation (54). The ratio of the corrected value of hydraulic gradient and "wet" vapour pressure, termed vapour distribution ratio, may now be calculated easily. If the vapour distribution ratio is larger than 0.5, the trap operation is unstable. In order to avoid

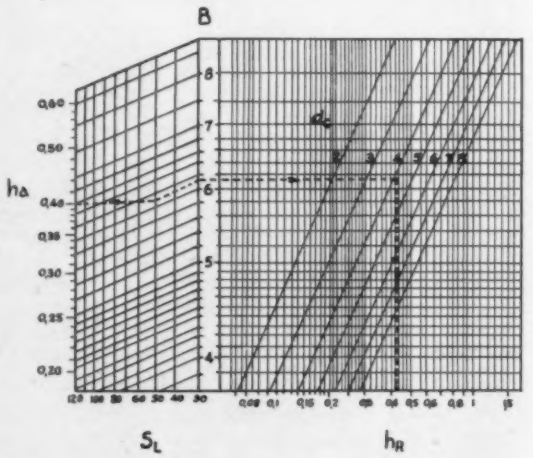

Fig. 4. Chart for determining pressure drop per cap on "wet" tray.

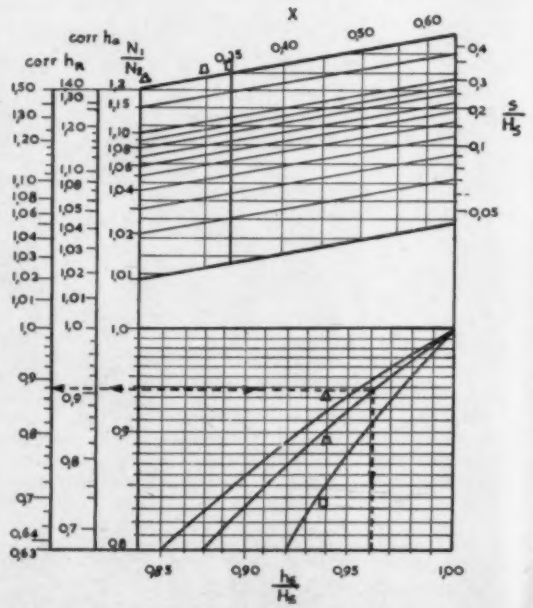

Fig. 5. The rapid solution of equations for maximum pressure drop through riser cap and slots on a "wet" tray.

this, it is advisable to diminish the number of cap rows by employing caps of larger diameters, which means a new tray layout.

All the data necessary for the calculation of the total pressure drop on the tray are thus available; the static submergence has been mentioned again together with the calculation of the weir height. Some indication on the minimum tray spacing is given by the value of the total vapour pressure drop, since the latter may only be half of the tray spacing at a maximum.

New Graphic Method

The derivations described may be also represented graphically. The graphic method is advantageous wherever the task to be performed is either frequently recurring, or if it necessitates series of trial-and-error calculations.

Taking into consideration the present and future of the chemical industries, distillation and absorption are among the operations appearing most frequently in the organic chemical, petroleum and petrochemical industries.

Although the method disclosed in this paper is very much simpler by comparison with the existing methods, now, some trial-and-error calculations are, however, unavoidable. Such is the case, for example, with the determination of the vapour distribution ratio, the height of weir crest, the hydraulic gradient, the pressure drop and possible correction of the latter.

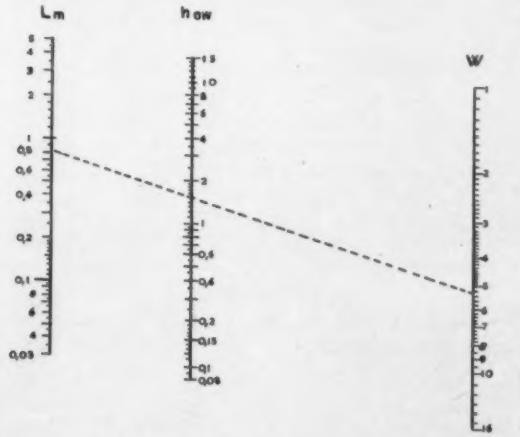

Fig. 6. Graphical determination of the height of liquid crest at a tray.

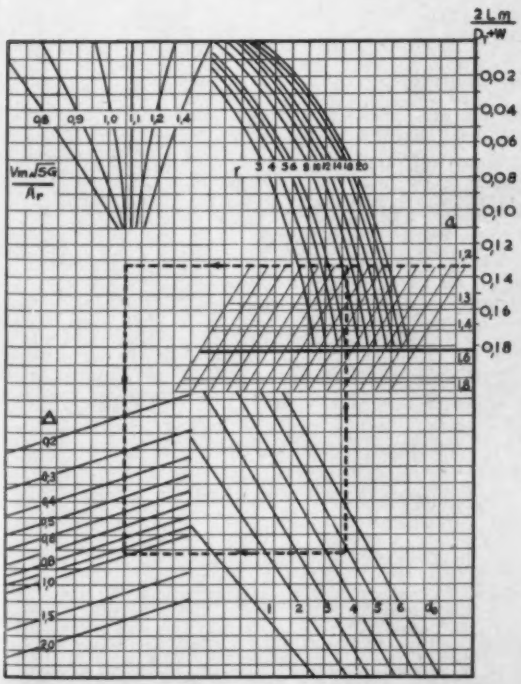

Fig. 7. Graphical determination of the hydraulic gradient upon a bubble-cap tray.

Figure 1

As shown in the previous paper, different cap spacings correspond to any cap sizings (d_c, H_S, C, X). This is expressed by Equation (1). According to Equation (7), each cap corresponds to a characteristic value of B, which depends, beside the slot length and cap spacing, also on the slot shape. Fig. 1 has been plotted to determine a and B belonging to caps of various sizes. Starting from d_c by proceeding as far as H_S, then to parameter X, the value of a is obtained. From here, proceeding along the oblique lines, as far as the vertical line corresponding to the various slot shapes, and from there horizontally, to reach the vertical line in the point $H_S = 0.6$. In the case of triangular slots, the oblique line need not be drawn, while with oblong slots the horizontal line is not necessary. The next step is to proceed along the oblique lines on the right side of the diagram as far as the desired value of H_S; the value B is obtained on the ordinate.

When standardised caps are available for the design, it is enough to determine the values a and B only once, and to use these values further on. If the caps are not standardised, Fig. 1 must be referred to frequently.

Figure 2

This figure represents Equation (23), and has been made possible by the fact that m also is a function of a. Starting from a, taken from Fig. 1, by proceeding to the value of B, which is also taken from Fig. 1, than to the value of P one obtains the value of ratio A_L/A_T. If standardised caps are available, the points for caps of various sizing may be shown on the abscissa. In this case, one has to proceed from the marked point on the abscissa to the value of P, and from there to A_L/A_T, and it is not necessary to cover the distance between a and B.

Figure 3

On the basis of value A_L/A_T, obtained from Fig. 2, by means of Equation (9) and utilising the values of P and B, the ratio A_c/A_T can be determined, from which the value of A/A_T can be obtained, according to Equation (11). These correlations have been plotted on the right-hand side of the diagram. They are used by starting from the value of A_L/A_T in such a way that first the straight line plotted for the value of B and then that for P must be intersected. A parallel line must be drawn from A_c/A_T to the oblique lines marked, as long as the vertical line corresponding to the value a obtained from Fig. 1 is not reached. A horizontal line drawn from this point then gives the value of A/A_T. Values A_L/A_T and A/A_T have been obtained from Figs. 2 and 3 respectively. According to Equation (12):

$$\frac{A}{A_T} + 2\frac{A_L}{A_T} = 1 - \frac{A'}{A_T}$$

Therefore, Figs. 2 and 3 render possible a quick and simple determination of the ratio of the end wastage + disengaging area and the tray cross-section. With tray of correct design, the value of A'/A_T amounts to a maximum of 15 per cent.

In connection with Equation (24a) it has been mentioned that the value of A' is not influenced by the liquid quantity. On this basis, it has been noted that the value of A'/A_T is

always smaller than 15 per cent if

$$\frac{12D}{d_c} = 16$$

On the left-hand side of Fig. 3, A_T and the corresponding value of D_T may be determined in a simple way from the values of A_L/A_T and L_m. A horizontal line is drawn from A_L/A_T, obtained from Fig. 2, as far as the oblique line intersecting L values. Thereupon, a line is drawn vertically to the abscissa, and the value of W/D_T obtained. From the latter, and from the value of D_T, the length of the weir may easily be calculated.

The oblique line represents the equation

$$\frac{A_L}{A_T} = \frac{1}{180} \text{ arc sin. } \frac{W}{D_T} - \frac{1}{\pi}\frac{W}{D_T}\sqrt{1-\left(\frac{W}{D_T}\right)^2}$$

The product of A_c/A_T, obtained on the right-hand side of Fig. 3, and of the value of A_T, read on the left-hand side, represents the sum A_c of the areas of the caps placed on the tray. On the basis of this, the required number of caps is readily obtained.

With the values obtained from Figs. 1 and 2, all the values are at disposal for the design of tray layout. The experience has shown that on a tray of diameter D_T, determined by the diagram, the number of caps, which can be placed so that between the weir and the outermost cap row, as well as between the column wall and the last caps enough space is left—3 in. and 1 in. respectively—the value of N_2 may differ by ± 10 per cent from the number N_1, obtained by direct reading.

As a rule, the number of caps read and that obtained by design are not in exact agreement with each other. This seems to be a contradiction to the first item of the assumptions given at the beginning of the present paper. It must be remembered, though, that the establishment of the maximum, as has been previously mentioned, is an estimate, and that the A_c value obtained from Equation (10) does not necessarily give a whole number for N_1; hence a rounding-off is inevitable. It is generally advisable not to alter the starting value, but to assume that either the slots are *almost* totally open, or, when maximum load is applied (i.e., only temporarily), a small part of the skirt clearance will also be involved. For the same reason, it is not worth while altering the cap spacing.

The tray layout designed by means of Figs. 1 to 3 must only be altered if A'/A_T is larger than 15 per cent, or if the outside cap row would be too near to or too far from the weir. Since the downcomer area together with the weir length has been exactly determined, the weir may be placed even farther from the outside cap row. If otherwise, the safety in the downcomer design is even increased by this. The caps may possibly be placed on the tray asymmetrically.

The usual experience is that even small modifications are seldom necessary, and in most cases the tray layout meets the most up-to-date requirements. It must, however, be mentioned that the method described does not allow for possible standards. Adaptation to standard column dimensions naturally involves certain modifications.

Figure 4

Equations (29) and (35) have been plotted on the right-hand side and the left-hand side respectively. In connection with the plotting of Equation (29), it must be mentioned that the effect of the variation of ρ_L has been neglected, since the variation of the value of h_R brought about by $\rho_L^{0.045}$ would amount to a few per cent only, if ρ_L varied between the ranges occurring in general practice. The value of h_R is read from the diagram, so that starting from the corresponding value of the calibration B in the middle and proceeding as far as the value of d_c employed, the vertical drawn to the abscissa from the intersecting point will give the value of h_R. On the left-hand side of the diagram the value h_a may be read, again starting at the value of B and proceeding along the oblique lines on the diagram so long as the ρ_L value on the abscissa is reached. Drawing the horizontal line from this point, the value of h_a can be read on the ordinate on the left-hand side. The numerical constant mentioned in connection with Equation (33) is, of course, not shown in the diagram.

Figure 5

All the corrected values, necessitated by the differences between the number of caps calculated and obtained in the design, may be read on this diagram.

The ratio N_1/N_2 has been plotted on the middle axis of the diagram, on its lower right-hand side of Equations (35) to (37); on the upper right-hand side there is the graphic solution of Equation (41). For the solution of the former, a horizontal line is drawn starting from such values of N_1/N_2 as are smaller than 1, proceeding to the curve representing the slot of corresponding shape, whereupon a vertical is drawn from the intersecting point to the abscissa. The latter step is done by starting from the values of N_1/N_2 larger than 1, along the oblique lines on the diagram, proceeding as far as the vertical corresponding to the slot shape employed, proceeding from here horizontally to the vertical over the point $X = 0.35$. In the case of triangular slots, it is not necessary to proceed along the oblique lines, whereas with oblong slots the above-mentioned horizontal line is not needed.

On the left-hand side of the diagram are shown the corrected values of h_R and h_a belonging to various ratios of N_1/N_2. The corrected values are as follows:

$$h_R(N_1/N_2)^{2.09} \text{ and } h_a(N_1/N_2)^{1.71}$$

Fig. 5 therefore renders possible the quick solution of Equations (42) and/or (43).

Figure 6

This diagram permits rapid solution of Equation (44). The values of L_m and the values for W are plotted on the left-hand side and the right-hand side of the diagram respectively. Connecting with a straight line, the maximum liquid quantity on the scale for L_m with the value of W, obtained on the scale for W of Fig. 3, the required value of h_{ow} may be read on the middle scale.

Figure 7

This diagram renders possible rapid reading of the hydraulic gradient. As a basis for plotting, this diagram served the assumption expressed in implicit form by Equation (54a). Since the factor C_d shown in equation (54) as well as the correction factor necessary in the case where $V_m/A_T\sqrt{\rho_G} = 1.1$, are functions of $L_m/(D_T + W)$, it has become possible to build both the factor C_d and the latter correction factor into the diagram, avoiding by this the application of any additional diagrams.

No trial-and-error calculations or assumptions are required by the use of this diagram. This seems to be the greatest advantage of these new methods as compared with diagrams of similar object, known to the authors of the present paper.

When using the diagram, the value of d_o must first be determined, then one should start from the value of $2L_m/(D_T + W)$, which has been plotted on the ordinate on the right-hand side. From here, a horizontal line is drawn as far as the curve among the fan-shaped family of curves on the left upper corner of the diagram where the value of $V_m/A_T\sqrt{\rho_G}$ is plotted, obtained from the initial data and previous operations.

A vertical line is drawn as far as the thick line represent-

ing the value $a = 1.5$, from the point where the above-mentioned horizontal line and the r value obtained from the tray layout intersect. If the value of a is not equal to 1.5, then one has to proceed as far as the a value required, along the oblique lines on the diagram; and on reaching this point a vertical line should be drawn to the calculated value of d_o. The intersection of the horizontal line, drawn from the intersection point to the lower left-hand side of the diagram, with the vertical line drawn from the calculated curve of $V_m/A_T\sqrt{\rho_G}$, will give the required value of $\triangle$. The diagram for the determination of the hydraulic gradient was published in metric units by the authors of the present paper previously.[15] The values obtained from the diagram and those received by the analytical solution of the DAVIES equation show only rather small differences. The inaccuracy involved by the plotting of the diagram seems to be amply compensated, when comparing the easy handling of the diagram with the intricate equation by DAVIES.

Worked Example Illustrating the Use of the Diagram

The example below will illustrate the series of diagrams. The individual steps in this calculation have been marked on the diagrams.

Required: Determination of the bubble-cap tray diameter and tray layout for the following data:

$$V_m\sqrt{\rho_G} = 36.4 \text{ ft}^3/\text{sec. } (\text{lb}/\text{ft}^3)^{\frac{1}{2}}$$
$$L = 0.822 \text{ ft}^3/\text{sec.}$$
$$\rho_L = 53.0 \text{ lb}/\text{ft}^3$$

Cap to be employed: a Bolles cap of 4 in. nominal diameter ($d_c = 4.09$ in., $H_S = 1.25$ in., $X = 0.506$, $S = 1.0$ in.) Tray layout must be verified by hydraulic analysis.

Solution:

A. Sizing Analysis

From Fig. 1 $a = 1.495$, $B = 6.15$

For the utilisation of Fig. 2 $P = \dfrac{0.822 \cdot \sqrt{53}}{36.4} = 0.164$

From Fig. 2 $A_L/A_T = 0.132$

From Fig. 3 $A_T = 37.5 \text{ ft}^2$, $D_T = 6.9 \text{ ft}$, $W/D_T = 0.78$, $A_c/A_T = 0.26$, $A/A_T = 0.64$

Calculated on the basis of the values taken from Fig. 3. $W = 5.38 \text{ ft}$, $A_c = 9.75 \text{ ft}^2$, $A = 24.00 \text{ ft}^2$, $A_L = 4.95 \text{ ft}^2$, $A' = 3.60 \text{ ft}^2$, $A'/A_T = 0.096$, $D_c = 3.52 \text{ ft}$, $D' = 2.14 \text{ ft}$

From Equation (14) from the calculated value of A, $D = 5.66 \text{ ft}$, $D = 5.52 \text{ ft}$, $N_1 = 107$

The tray layout designed on the basis of the above sizing analysis is shown on Fig. 1.

B. Hydraulic Analysis

From the tray layout $N_2 = 114$, $r = 9$

From Fig. 4 $h_B = 0.43$ in., $h_a = 0.40$ in.

From Fig. 5 $\dfrac{N_1}{N_2} = 0.938$

From Fig. 6 $\dfrac{h_s}{H_s} = 0.96$

Correction factor to h_B: 0.88

Correction factor to h_a: 0.905

Calculated from the values taken from Figs. 4 and 5 $h_S = 1.20$ in., h_B, corrected $= 0.39$ in., h_a, corrected $= 0.36$ in.

From Fig. 6 $h_{ow} = 1.5$ in.

For the utilisation of Fig. 7 $\dfrac{D_T + W}{2} = 6.14 \text{ ft}$

$\dfrac{2L}{D_T + W} = 0.134 \text{ ft}^3/\text{sec. ft}$, $h_{st} = 1.0$ in., $d_o = 4.75$ in.

$\dfrac{V_m}{A_T}\sqrt{\rho_G} = 0.97 \text{ ft/sec. } (\text{lb}/\text{ft}^2)^{\frac{1}{2}}$

From Fig. 7 $\triangle = 0.95$ in.

Calculated from values taken from Figs. 4 and 7

$$h = 0.39 + 0.36 + 1.20 = 1.95 \text{ in.}$$
$$\frac{\triangle}{h} = \frac{0.95}{1.95} = 0.49$$
$$h_t = 1.95 + 1.00 + 1.50 + 0.47 = 4.91 \text{ in.}$$

Conclusions

Following upon their previous paper, the conception of the "equivalent diameter" has been used by the authors for the purpose of bubble-cap tray design. The considerations of the previous paper covering the problem of cap spacing, as well as the equivalent diameter theory, have resulted in simple correlations, which make possible the carrying through of the bubble-cap tray sizing analysis rapidly with the accuracy required. At the beginning of the design, the total effect of the vapour/gas *and* liquid loads is taken into consideration. From a *theoretical* viewpoint, this means that an analogy has been drawn between the determination of the cross-sections of packed columns and those of columns with bubble-cap trays.

From a *practical* viewpoint, the trial-and-error calculations involved in the utilisation of the F factor used in the method by DAVIES for the determination of the allocation of downflow area may be avoided by means of the new correlations. The necessary correlations for the sizing analysis may be suitably plotted on the diagrams, which are easy to handle and render the work of the designer easier and faster.

The verification of the sizing analysis is carried out by hydraulic analysis. The conventional correlations used for this purpose have been transformed by the authors by applying slight approximations, in order to emphasise the importance of the constant B, characterising the cap employed. The correlations thus transformed may also be represented by simple diagrams.

The two diagrams plotted for the sizing analysis and hydraulic analysis make possible the determination and checking of all the possible sizings. For this purpose, only the knowledge of the static submergence is required apart from the dimensions of the cap employed.

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Fig. 1. Control room of the chemical converting plant in the sulphite mill.

CHEMICAL RECOVERY IN SWEDISH SULPHITE PULP PROCESS

Complete independence of sulphate and sulphite methods of wood pulp production, the use of pine wood as a raw material along with wide range grading of the pulp produced are some of the advantages possessed by a new process which employs a two-stage chlorine dioxide bleaching process

MAKING possible the almost complete recovery of the expensive chemicals used in the sodium sulphite method of wood pulp manufacture, and thereby contributing greatly to the placing of the sulphite method on a better economic basis, a unique process of chemical recovery has been developed in Sweden by Stora Kopparbergs Bergslags A.B. of Skutskär, Sweden. Originally developed by Stora's Central Research Laboratory at Falun in collaboration with the mill, this new recovery process has been in operation by the company on a full mill scale since 1958. In this final form, too, it has been in operation in the sulphite mill of Mo och Domsjo at Ornsköldsvik, Sweden, for over a year.

Hitherto, although for the sulphate method of producing wood pulp there had been a complete chemical recovery process, the recovery of chemicals from the sulphite method depended on their being re-used in the sulphate mill. While this combination of sulphite and sulphate processes presented a simple and economical solution in respect of the re-use of the chemicals, it necessitated the sulphate mill being of a certain minimum capacity in relation to the sulphite mill fully to utilise the chemicals from the latter. It also made the sulphite mill completely dependent on the sulphate mill in this respect.

The new recovery process achieves complete independence of the sulphite mill from the sulphate mill and is now being used at Skutskär as part of a new bleached sulphite pulp production method which also makes possible the use of pine wood, the wood material chiefly available to the company.

Under the normal cooking conditions employed in the conventional sulphite method, the phenolic extractives and the lignin of the pine wood are subjected to condensation reactions that make impossible the separation of the fibres.

Preventing Condensation Reaction

In order to prevent these condensation reactions from occurring prior to the removal of the lignin, the new sulphite process involves cooking of the wood in two stages, each with different pH conditions. In the first stage, the wood is impregnated and partly sulphonated with an almost neutral cooking liquid. In the second stage, the lignin is removed under acid conditions.

An important requirement of this process was that a base be used which yielded a highly soluble bisulphite, and sodium base was found to give the best results, though the

use of expensive sodium salts called for an effective recovery system to cut down costs. Because of the mild conditions under which the wood is now cooked by this method, there is less hydrolytic destruction of the valuable hemicellulose components compared with the normal sulphite process. The new method also makes possible the grading of the quality characteristics of the pulp over a much wider range. Furthermore, to eliminate the destructive effect of bleaching agents on the carbohydrates, a new bleaching method without any stage of hypochlorite bleaching, but with two chlorine dioxide bleaching stages, was incorporated into the production process. By this new method, bleaching of the sulphite pulp is carried out on the same lines as in the most up-to-date sulphate bleaching plants, but under still milder bleaching conditions and with chemically purified water. Screening after bleaching is also carried out in a plant equipped with centri-cleaner batteries of the latest design.

In its present form, the chemical recovery system for the sulphite process achieves a high yield of chemicals and a trace formation of sodium thiosulphate and, since it deals only with gases and liquids, lends itself ideally to continuous operation and fully automatic control.

Chemical Recovery System

On leaving the pulp cooking process, the spent acid liquor (red liquor) is evaporated and then burnt in a recovery furnace. The smelt solution then passes to the recovery system which consists of four main sections: the carbonating and decarbonating towers for carbonating and stripping the smelt solution and for converting the obtained sodium carbonate-bicarbonate solution to sodium sulphite; the Claus reactors, where the carbon dioxide is freed from hydrogen sulphide by conversion of the latter to elemental sulphur; the units for producing and concentrating sulphur dioxide; and scrubbers for absorbing sulphur dioxide from the boiler flue-gas.

The smelt from the recovery furnace, which consists principally of sodium carbonate and sodium sulphide, is first dissolved in water, giving a concentration of 100-130 gm of active Na_2O per litre, with a sulphidity of about 75 per cent. After being clarified by settling, this solution is continuously diluted to 70 gm Na_2O per litre.

Before going to the main carbonating tower this liquor is precarbonated in a smaller vessel to facilitate the stripping of hydrogen sulphide from the solution in the main tower. In this precarbonating tower, some scaling occurs because of the lowered pH value.

Green Liquor Treatment

The precarbonated liquor is fed into the top of the carbonating tower at a temperature of 70-75°C, and here it is treated with pure carbon dioxide which is fed into the bottom of the tower. This carbon dioxide consists of gas recirculated from the top of the tower through the Claus reactor together with the carbon dioxide liberated in the decarbonating process which, following the carbonating tower, converts sodium carbonate-bicarbonate to sodium sulphite. Treatment of the green liquor with carbon dioxide in the carbonating tower removes the sulphide sulphur as H_2S, the sodium salts remaining in the solution as $NaHCO_3$. The gas leaving the top of the tower thus consists of water vapour, plus 16-18 per cent hydrogen sulphide and 82-84 per cent carbon dioxide calculated on a dry basis. By cooling the gas to 40°C, most of the water is condensed and the remaining gas passes through a rotary blower to the modified Claus reactor gas purification system, where the hydrogen sulphide is converted to elemental sulphur.

Each of the two vertical reaction towers which, in series,

Fig. 2. Bleaching towers in the sulphite bleaching plant.

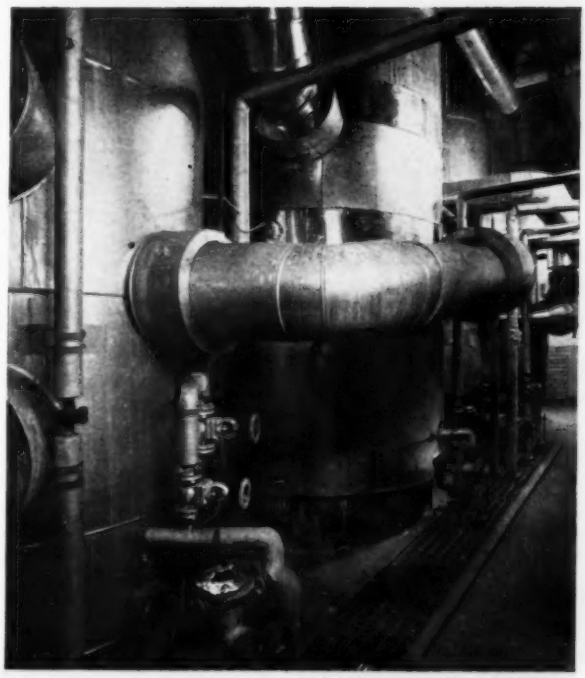

Fig. 3. Reaction towers in the chemical converting plant.

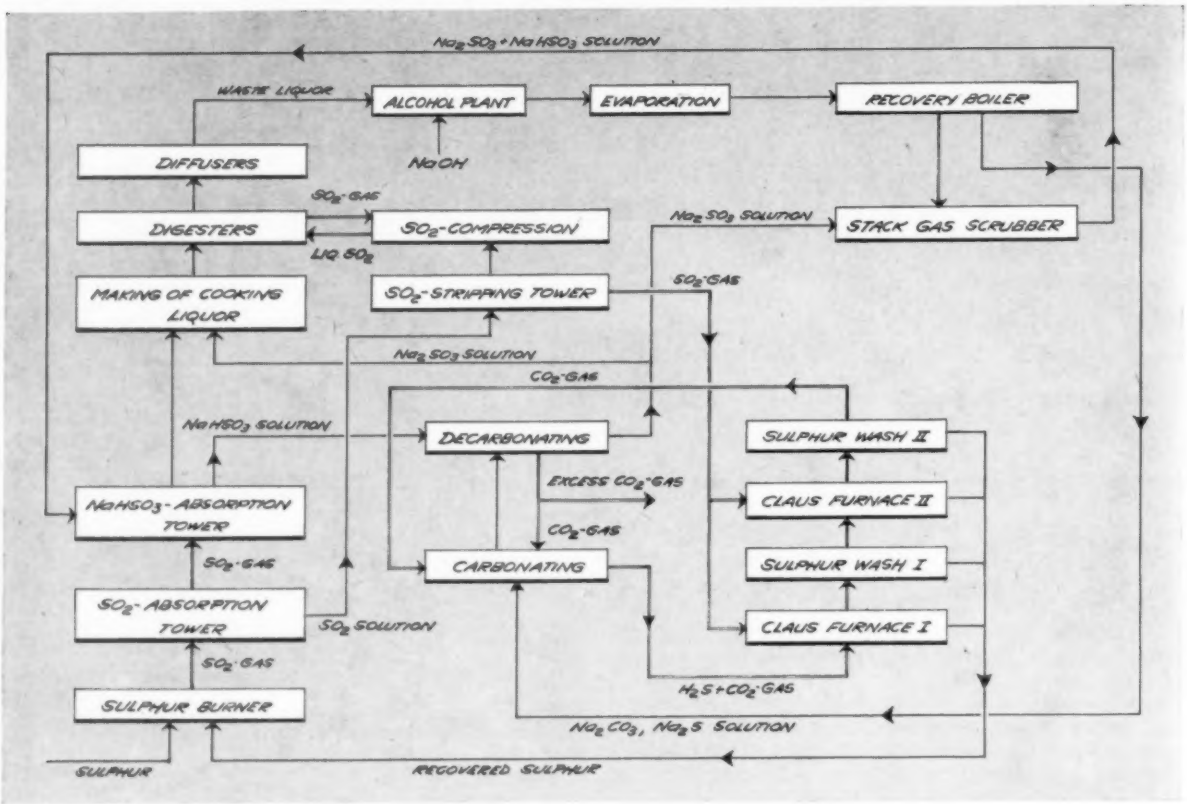

Fig. 4. Flow of materials in the new Swedish chemical process at Skutskär.

make up the Claus unit has two catalyst beds and two preheaters. The cooled carbon dioxide-hydrogen sulphide gas mixture from the carbonating tower is first preheated to about 300°C before being mixed with an adequate amount of sulphur dioxide prior to entering the upper catalyst bed in the first reactor. After passing the lower bed and a washing stage, the gas, now much poorer in hydrogen sulphide, is again preheated, this time to 240°C, before entering the second stage. In the process of reaction, which is exothermic, water vapour and elemental sulphur are formed, the liberated heat being transferred in the preheaters to the ingoing gas. While the higher temperature of the first reactor produces faster reaction, the lower temperature of the second produces more complete reaction. The catalyst in the bed of the second reactor also has a higher activity than the low-cost catalyst in the first reactor.

Washing Reaction Tower Gases

Washing of the outgoing gas from each reaction tower is effected by circulating liquid sulphur in a scrubbing tower to remove the gaseous and sublimated sulphur. The liquid sulphur enters each of the scrubbing towers at 135-140°C and leaves at about 150°C, whereupon it is cooled in a heat exchanger. The heat given off in the exchanger is used to produce steam, which, in turn, heats the decarbonating tower.

The conversion of hydrogen sulphide to elemental sulphur is for all practical purposes complete, and the carbon dioxide leaving the system can be recycled to the base of the carbonating tower without further purification. The sulphur produced, together with make-up sulphur, is fed to a sulphur burner to produce sulphur dioxide. So that the gas from the burner shall be free of oxygen and inert gases, before being sent to the compressors to produce liquid SO_2 for the second stage cook, and to the Claus reactor, it is passed through an absorption tower, where part of the sulphur dioxide is absorbed in 12°C water to form a 2 per cent aqueous solution. This is then heated in a stripper to produce pure sulphur dioxide gas. Part of this gas is dried and cooled and passes on to a compressor to form pure liquid SO_2, while the rest goes to the Claus reactor.

That part of the burner gas not absorbed in the water scrubber passes from the top of the scrubber to a second absorption tower where sulphur dioxide is absorbed in a sodium sulphite-bisulphite solution, producing a bisulphite solution. The latter, at a concentration of about 70 gm/litre Na_2O is used in the decarbonating tower to convert the sodium carbonate-bicarbonate solution to sodium sulphite. This, in turn, is used in an absorption tower for the recovery of sulphur dioxide from the recovery boiler flue gas. This absorption tower must be carefully designed and operated in order to prevent the formation of sulphate. To this end, the contact time should be short and the sodium sulphite concentration on the high side. Even so, from 10-20 per cent of the recovered sulphur is oxidised to sulphate. The

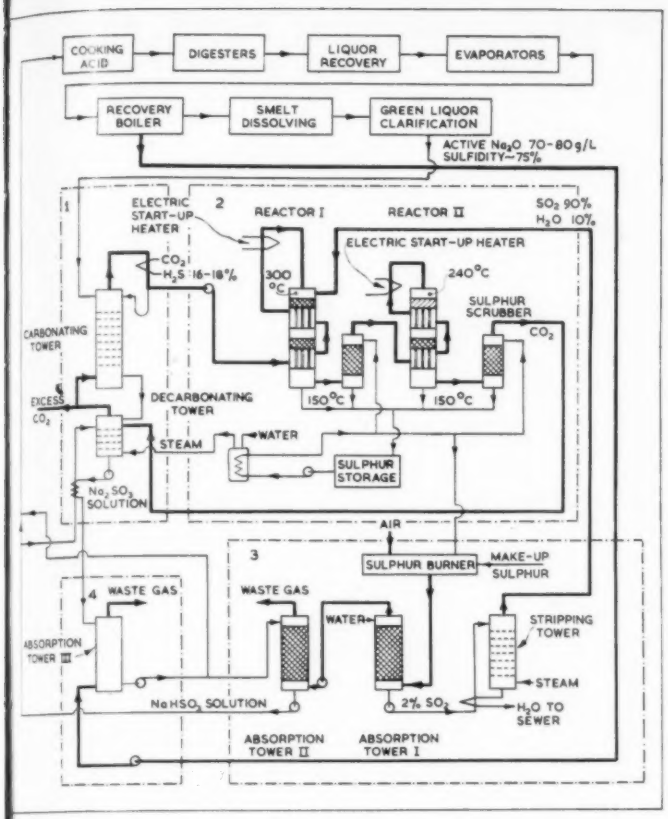

Fig. 5. Flow diagram of the Stora sodium-base chemical recovery process.

resulting solution of sodium sulphite and bisulphite from the flue gas scrubber is used for the absorption of sulphur dioxide from the burner gas as previously described.

Conditions for Claus Reaction

In order to achieve the best equilibrium conditions from the Claus reaction, temperatures should be kept as low as possible and in several steps with intermediate cooling and removal of elemental sulphur to keep excess sulphur dioxide as low as possible.

Reverting now to the carbonating process and the treatment of the sodium salts, these descend, chiefly in the form of $NaHCO_3$ solution, from the carbonating tower to a decarbonating tower. Here, sodium bisulphite from the cooking liquor preparation and steam heat are added to decarbonate the liquor and this results in a solution of sodium sulphite (Na_2SO_3) plus carbon dioxide gas. The latter forms part of the gas feed to the carbonating tower, while the former is first passed through absorption towers for the recovery of sulphur dioxide from the recovery boiler flue gas, as previously mentioned, before being used for cooking liquor. Since CO_2 is obtained both from gas leaving the carbonating tower and from the decarbonating tower, there is an excess supply of this which is continuously drawn off.

When the four sections of the chemical recovery system are working efficiently only about 1 per cent of thiosulphate of the total amount of active Na_2O is formed. Since this does not affect the pulping process, the small amount of elemental sulphur remaining in the gas leaving the Claus unit is not removed. It is absorbed in the decarbonating tower with some increase in the thiosulphate concentration which, however, never exceeds 4 per cent.

Chemical loss during recovery is very small, there being no loss in the first two sections and a loss of only 4-5 kg of sulphur per ton of pulp in the third and fourth sections. There is also a normal small loss of sodium, not exceeding 2-3 kg/Na_2O per ton of pulp in the absorption systems.

Fluidisation Symposium

AT the first Symposium on Fluidisation to be held in London by the Institution of Chemical Engineers nine papers are to be given during this single-day event.

DR. S. R. TAILBY (Battersea College of Technology) will describe an investigation of the residence time of solids in a system consisting of glass beads fluidised with air. The variables selected in this investigation are the length to diameter ratio of the fluidised bed, the flow rate of fluidising gas and the flow rate of solids. The effect of these variables on the solids flow pattern is interpreted by comparison with theoretical knowledge.

A survey of research in the field carried out by the Chemical Engineering Division of A.E.R.E. Harwell will be presented by J. B. LEWIS. The same establishment also provides the authors for a number of other papers. Thus, P. F. WACE and S. J. BURNETT will describe experiments to detect the direction and velocity of gas streams passing through fluidised beds. They have found that pressure gradients occur towards the bases of void spaces and give rise to horizontal drag forces on particles which cause rapid changes in direction of the local gas flow.

P. N. ROWE is to deliver a paper entitled "Drag Forces in a Hydraulic Model of a Fluidised Bed". With W. M. STAPLETON (also of Harwell), Mr. ROWE is to describe observations made upon gas fluidised beds in a 12 in. diameter column. A final paper from the Harwell establishment will be given by K. S. SUTHERLAND and is entitled "Solids Mixing Studies in Gas Fluidised Beds".

In their paper, "On the Nature of Aggregative and Particulate Fluidisation", three authors from the University of Cambridge, D. HARRISON, J. F. DAVIDSON and J. W. DE KOK, put forward a theory to explain the nature of aggregative (bubbling) and particulate (smooth) fluidisation. This theory is discussed in relation to the information it can offer on (a) the quality of fluidisation and the problems of scale-up, and (b) the effect of temperature on fluidisation.

The final paper in this symposium is to be given by J. F. RICHARDSON and J. SZEKELY (Imperial College of Science and Technology, London) and is devoted to mass transfer in fluidised beds.

The Symposium commences at 2.30 p.m. and finishes at 7 p.m. on 7 March, 1961. It is to be held at Burlington House, London, W.1.

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THE CORROSION RESISTANCE OF SOME SPRAYED METALLIC COATINGS

The applications of sprayed metallic coatings in corrosive environments are reviewed. Experimental results show that the success of some coatings is due to their ability to provide cathodic protection. Chemical blocking may also modify such sacrificial behaviour so as to develop a more durable surface

by T. K. ROSS and E. L. SMITH

Introduction

METAL spraying is now established as an important means of protecting iron and steel against corrosion.[1] Early developments were influenced by past experience with zinc galvanising, and zinc spraying was fairly common before the war. The relationship between coat thickness and protection afforded to the steel was shown to be a direct one.[2] These tests indicated protective lives of up to ten years in industrial atmospheres and six years in sea-water. As early as 1928 EVANS had shown that sprayed aluminium held promise as a protective coating on steel, and later with BRITTON[4] suggested that lives of up to seven years were possible. MANSFORD,[1] in reviewing these and other results, has shown their application to sea-water immersion tests. HOAR[5] has continued tests to compare the behaviour of duplex coatings which show that those prepared from zinc-aluminium alloys are superior to those consisting of single or duplex layers of either metal alone.

The mechanism of the protective process is still a matter of scientific interest. The early work of EVANS[3] suggested that the basis of protection was a cathodic one, and that as long as any coating remained upon the steel it behaved as a connected sacrificial anode. However, the relative potentials of steel and sprayed coats of zinc or aluminium depend upon the conditions of exposure. TOLLEY[6] has shown, for example, that sprayed aluminium is often initially cathodic to steel, only becoming anodic as its protective oxide film breaks down. MAYNE and VAN ROOYEN[7] have shown that this is more particularly true in hard waters, the aluminium being anodic from the outset in saline waters.

Mechanisms other than cathodic processes have been suggested as being responsible for the protection of steel, and MAYNE and VAN ROOYEN[7] deduce evidence for pore-sealing reactions subsequent to immersion of aluminium-

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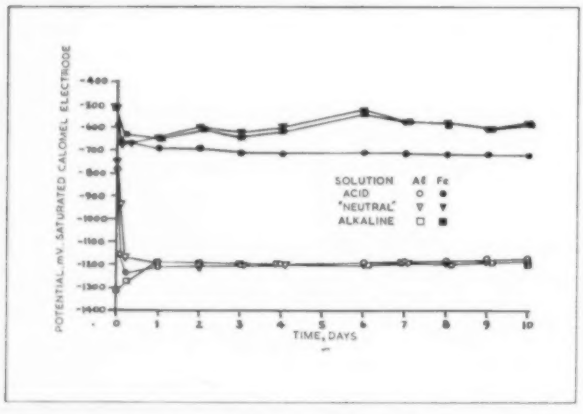

Fig. 1. Potential measurements with 99.99% Al-mild steel couples.

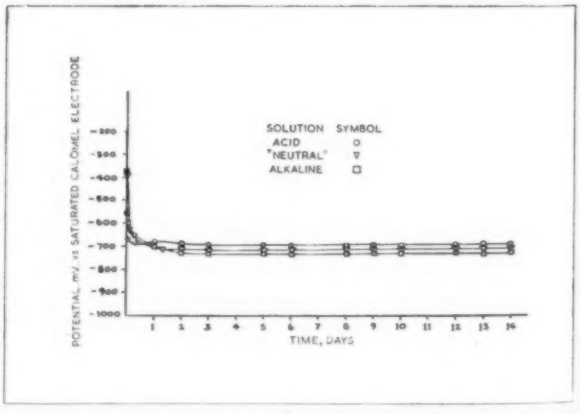

Fig. 2. Potential measurements with shot-blasted mild steel panels.

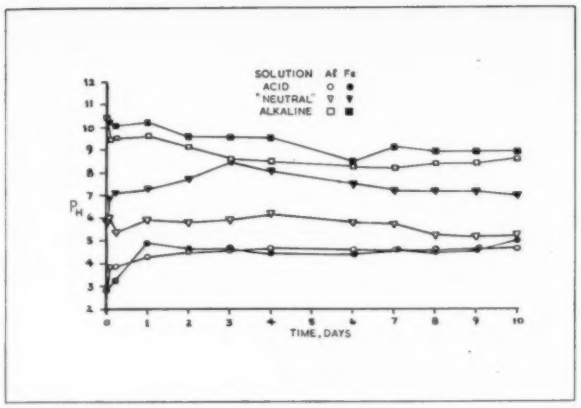

Fig. 3. pH measurements with 99.99% Al-mild steel couples.

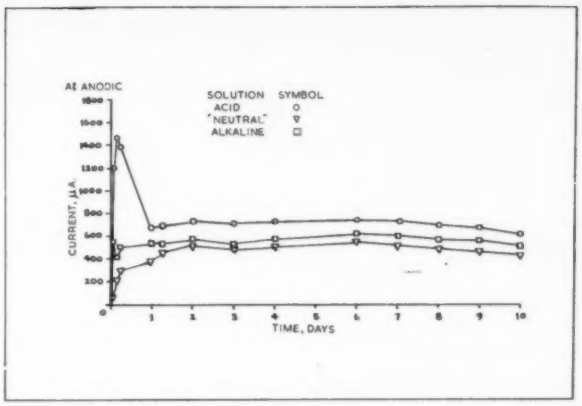

Fig. 4. Current measurements with 99.99% Al-mild steel couples.

sprayed steel in supply waters, a matter referred to also by DE PAAUW.[8] Thus, zinc coatings, according to the latter author, experienced a 90% reduction of porosity in one day and a 98% reduction in one week, whilst aluminium suffered a 50% reduction under similar conditions. Not only corrosion products from the sprayed metal, but those formed by exposed steel may assist in this process, according to BALLARD.[9]

Thus it would appear that both cathodic and pore-blocking processes are responsible for the protection of steel by means of sprayed coatings of zinc or aluminium.

Experimental Work

In chemical engineering applications it is important to know which mechanism may predominate under typical conditions of exposure, for the extremes of corrosive action encountered render the balance between them very critical. Thus, although pore blocking could be regarded as an important protective mechanism in ordinary urban atmospheres, the conditions in a chemical works are such that soluble corrosion products could be formed, and little blocking would result. The protection of steel and steel-structures under such conditions would then depend upon some level of cathodic protection. Some experimental work was designed to indicate the role of these mechanisms in the case of aluminium, zinc and magnesium applied to mild steel as sprayed coatings. Zinc and aluminium are usual materials for this application, and magnesium was included because of its extreme anodic behaviour to steel, so that it might serve as a comparison to the more usual metals. Both BALLARD[10] and BRITTON and EVANS[4] had suggested that the purity of the aluminium was a factor in protective behaviour, and "super-pure" grade (99.99% Al) was therefore selected for these tests. Zinc of 99.95% purity and magnesium of 99.5% purity were also used.

Foils of all three metals, 5 mils thick, were prepared by spraying on to shot-blasted perspex sheet measuring 6 in. × 2 in. × $\frac{1}{16}$ in. from a Mark 16 pistol manufactured by Metallisation Ltd. of Dudley, Worcestershire. The fuel gases were acetylene and oxygen, both at 25 psi, and the propellant was air at 55 psi. Zinc and magnesium were sprayed from 2-mm wire and aluminium from $\frac{1}{8}$-in. wire. The edges of the specimens were sealed with a high melting point wax. Mild steel panels 6 in. × 2 in. were cut from 20-gauge bright rolled strip to B.S.S. 970 En 2, and shot-blasted before being wax coated on the back and edges.

Pairs of foils and mild-steel panels were mounted face to face in a plastic holder with electrical connections to each strip of metal. They were then immersed vertically to a depth of 4 in. in 700 ml of test solution in 800-ml beakers and maintained at 25°C. A calomel electrode and glass electrode were also mounted in each beaker.

The test solutions consisted of 0.001 N sodium chloride solution, the initial pH of which was adjusted to 2.9, 5.6 or

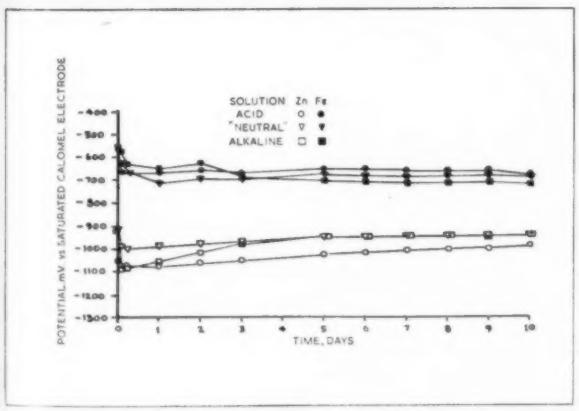

Fig. 5. Potential measurements with Zn-mild steel couples.

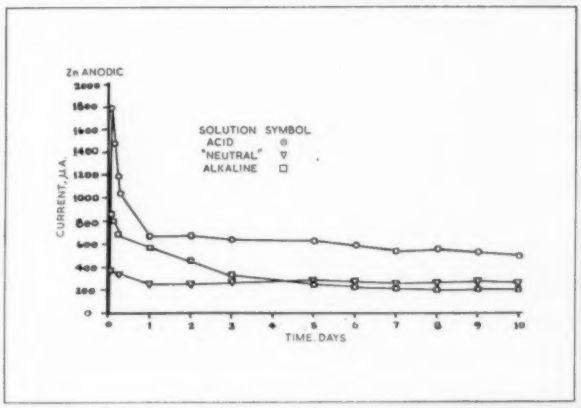

Fig. 6. Current measurements with Zn-mild steel couples.

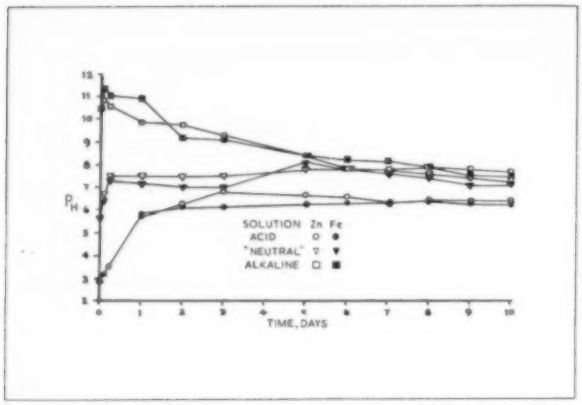

Fig. 7. pH measurements with Zn-mild steel couples.

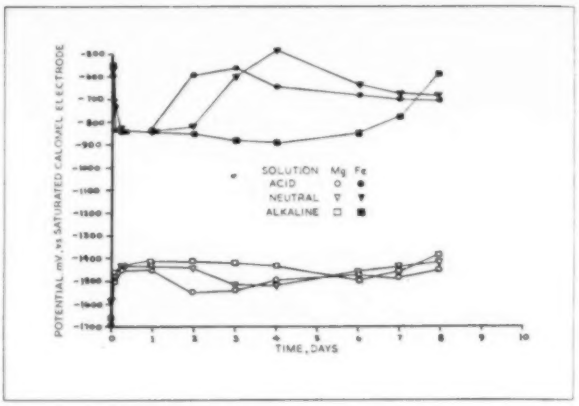

Fig. 8. Potential measurements with Mg-mild steel couples.

10.5—subsequently referred to as acid, neutral or alkaline test conditions. The foils and mild-steel panels were short-circuited during test, but by means of an external circuit the open-circuit potential of each specimen could be measured, or the current flow between a pair of specimens observed on a bank of "zero-resistance" ammeters. Also the pH of the test solution close to the metal strip was measured during the period of test.

Results

Aluminium

Fig. 1 shows how the initial nobility of the aluminium foil rapidly breaks down, and an open-circuit potential of about −1200 mV with respect to the calomel electrode becomes established. Comparison with Fig. 2, which shows the potential of steel panels alone exposed to similar conditions, suggests that the steel is rendered some 100 mV more positive when coupled to aluminium. It is also noticeable that the pH near the steel panel increases as corrosion proceeds (Fig. 3). The current flow between couples of steel and aluminium (Fig. 4) varied substantially during the first few hours of test (particularly so in acidic conditions), but was fairly constant after the first day. Both the aluminium foil and steel panel in acid solutions evolved hydrogen up to the eighth day, and the aluminium remained bright in appearance. In neutral and alkaline conditions gas evolution was less vigorous, and a dark stain formed on the sprayed aluminium. In all cases there was virtually no rust staining of the steel surface.

Zinc

As Fig. 5 and 6 show, both the potential and current conditions with coupled zinc were steady after the first day, and the potential of the steel surface was little changed from that of uncoupled steel. The solution near both steel and zinc tended to become roughly neutral after some days' exposure (Fig. 7). Some gas evolution from the zinc was observed, but was in general very much less than in the case of aluminium. Some rusting of the steel panels was observed.

Magnesium

As expected, the reactivity of the magnesium foils coupled to steel was such that their life was limited. Thus the potential of the connected steel was initially very negative, becoming a little less negative as the magnesium was destroyed (Fig. 8). The current flow (Fig. 9) also shows the rapid dissolution of magnesium; the pH of the solution likewise rapidly attained an alkaline value (Fig. 10). Vigorous gas evolution attended all these experiments, and whilst initially the steel remained free from rust, staining developed after the second day of immersion. However, bulky magnesium corrosion products appeared to stifle much subsequent activity at the steel surface.

Conclusions

The results show that some measure of cathodic protection is afforded to an equal area of connected mild steel by all three sprayed metals under the conditions described. The amount of this protection, and its persistence, as well

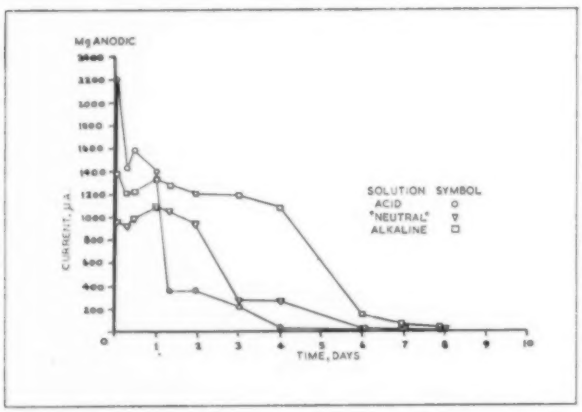

Fig. 9. Current measurements with Mg-mild steel couples.

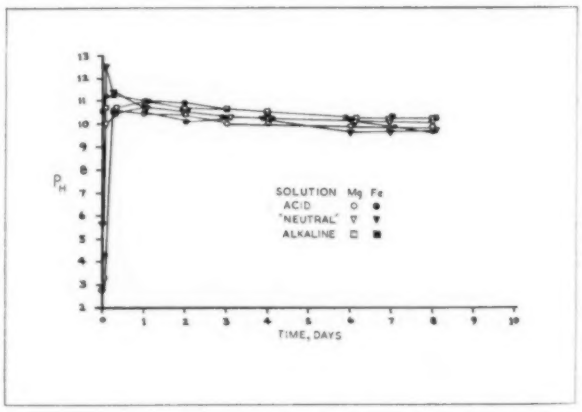

Fig. 10. pH measurements with Mg-mild steel couples.

as the degree of additional protection from chemical blocking is, however, different. Aluminium is able to give strong cathodic protection during the dangerous initial period of any new corrosive condition. This is true of acid, neutral and alkaline conditions, and the attack is controlled over long periods by these means. Zinc, on the other hand, establishes a steadiness of potential and pH which suggests a high level of chemical blocking. The initial condition of the test solution is soon equalised, as the pH observations show. Thus aluminium would be capable of responding to rapid changes of corrosive condition, by an almost immediate response of cathodic protection. Zinc, on the other hand, would rely more upon the steady build up of a chemically stabilised surface layer. Magnesium is so reactive as to have little attraction as an engineering material, but its violent cathodic behaviour before exhaustion and the stabilising effect of its corrosion products are indicative of the extremes of behaviour which may be attributed to the other two metals.

The test conditions were designed to represent those likely to be encountered in chemical works' atmospheres, and the exposure of the specimens was a deliberate exaggeration of the conditions to be expected over relatively small areas of porosity or damage that occur on sprayed surfaces. Nevertheless, the general conclusions as to the relation between cathodic protection and chemical blocking would apply with even more force to conditions where the geometry is so much more favourable.

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An Improved Carbon Disulphide Process

FOR many years carbon disulphide has been produced on a commercial scale by the direct combination of sulphur and carbon, the latter being usually in the form of charcoal. At least two variants of this process have been practised, the main difference lying in the method of supplying heat to the reaction which is carried out at a temperature in the range 800-1000°C. In the retort process, which is probably the most widely used at present, the reaction is carried out in direct fired retorts, while in the more modern variant the process is carried out in an electric-resistance furnace, the power requirement for heat being of the order of 800-1000 kWh/ton of CS_2 produced.

Another more modern process uses natural gas as the source of carbon, and requires a catalyst—usually an alumina type with a trace of chromium oxide—for its 700°C vapour-phase reaction. No plants using this route are more than ten years old. Another potential source of CS_2 is based upon the interaction of methane H_2S and oxygen, but this so far has not reached the commercial stage.

The latest development in the field, the outcome of research led by the main pioneer of the methane process, C. M. THACKER, of Taylor Fibre Co. (Norristown, Pa., U.S.A.), uses inexpensive petroleum fractions as the carbon source.

The process has a number of advantages over the methane process and it overcomes one of the main shortcomings of methane as a source of carbon, the large quantity of H_2S produced by the latter process; the retort and electrothermal processes of course, are quite free from this same disadvantage.

According to the most recent evaluation studies the liquid petroleum process will cost about 25 per cent less in plant investment and 15 per cent less in production costs than the methane process. The capacity of the facility can be determined primarily by the expected demand for carbon disulphide in the manufacturer's trading area rather than by the economics of volume production.

The greater flexibility in transporting liquid petroleum products can alter radically the economics of CS_2 plant location. Since, despite modern developments in transport of liquefied methane, it can only be transported economically in larger volumes, plants using methane must be located either at methane-gas-producing centres or along methane gas pipelines; the use of methane in many areas of the world is ruled out, quite apart from such process consideration as the H_2S by-product. By contrast, *liquid petroleum fractions* can be transported economically by a variety of means—pipelines, sea-going tankers, tank cars and tank trucks—hence carbon disulphide plants using the new process could be located anywhere within reach of these modes of transportation.

Many of the advantages possessed by this process over the methane process stem from the lower hydrogen to carbon ratio of the petroleum fraction used as the source of carbon. The reduced proportion of hydrogen sulphide which we mentioned at the outset means that the H_2S treatment and sulphur-recovery part of a plant operating this process is much smaller, the yield of CS_2 if the very heavy residuums are used as feedstock is double that obtained from methane per lb mol of reacted gases, and refrigeration requirements are appreciably lower.

Other important advantages are: the lower cost of the carbon source, especially if the petroleum fraction contains sulphur; the suitability for low-volume production as required by plants using CS_2 for processing purposes (e.g., rayon manufacture); the distinct possibilities for its adoption by existing methane plants to enlarge the capacity of the latter.

Details of a comparison made by Thacker of the two processes are given in Table I.

TABLE 1—Comparison of Methane Versus Liquid Petroleum Fractions in the Manufacture of Carbon Disulphide

Basis:	One Pass through Converter		
Methane process:	$CH_4 + 4.4S = 0.75CS_2 + 0.25CH_4 + 1.5H_2S + 1.4S$		
Fuel oil process:			
Fuel oil	$CH_{1.4} + 2.97S = CS_2 + 0.7H_2S + 0.27S$		
Heavy residuum	$CH + 2.75S = CS_2 + 0.5H_2S + 0.25S$		
		(Approximate Values)	
Process:	Methane	Petroleum Liquid	
Feed:	Methane	Gas Oil	Heavy Residuum
Ratio of carbon to hydrogen atoms in molecule	1:4	1:1.4	1:1
Feed needs purification before use	Yes	No	No
Economical transportation other than by pipe line	No	Yes	Yes
Assumed conversion per pass	75%	100%	100%
Sulphur (lb/ton CS_2 Produced):			
To vaporize and superheat	4940	2501	2316
To recycle:			
From sulphur feed	1572	227	211
From H_2S oxidation	1684	589	421
Total	3256	816	632
Recovery and Purification (After sulphur removal from reacted gases):			
Moles CS_2 per 100 moles reacted gases	30	41	67
Moles gases to condenser per ton CS_2 produced	88	45	39

The process is available for pilot-plant development by interested companies. The main feature requiring development is the reaction system, which has been proven on the small scale.

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EFFECT OF PARTICLE SIZE DISTRIBUTION IN FLUIDISATION

PART II

Classification and Elutriation

Apparatus and techniques are described for fluidisation of particles, pre-sized with a wide size range. A special probe enables multiple samples to be taken from the bed. It is shown that classification within the bed occurs with an accumulation of fines in a zone near the surface. This zone restricts the elutriation of the fines from the bed

by W. J. THOMAS, P. J. GREY* and S. B. WATKINS

THERE have been many contradictory statements concerning the degree of mixing occurring in fluidised beds. One of the aims of the present work was to establish the extent to which classification of solids occurs in a bed especially when dealing with a wide range of particle sizes. A special sampling device was designed to obtain simultaneous multiple samples in a vertical plane in the bed. The vertical sampler could be moved laterally so that samples could be obtained in different positions between the wall and the centre of the tube.

Elutriation of particles from the bed was also examined, a high efficiency cyclone being used to collect the elutriated material.

The samples from the bed and the elutriated material were examined by the processes of sieving, sedimentation and photo-extinction as described in Part I (February).

Symbols Used

a_0 = surface area of particles per unit volume of packed space, sq. ft/cu. ft;
a = constant depending on the segregation tendency;
g_c = conversion factor: 32.17 ft lb/lb force, sec^2;
k = elutriation constant;
L = height of settled bed, ft;
L_f = height of fluidised bed, ft;
L_I = length of flow path between segregation zones, ft;
P = pressure drop, lb/sq. ft;
X = weight of fines in the bed at time θ, gm;
X_0 = weight of fines in the bed at zero time, gm;
u_0 = superficial velocity of fluid through the bed;
ϵ_1, ϵ_2 = average fraction of voids above two neighbouring zones 1 and 2;
ϵ_3 = average fraction of voidage in the path of fluid segregating from zone 1 to zone 2;
ρ_s = particle density, lb mass/cu. ft;
ρ_F = fluid density, lb mass/cu. ft;
μ = fluid viscosity, lb mass/ft sec. or microns;
t or θ = time, hr.

Fluidisation Apparatus

The arrangement of the fluidisation apparatus is shown in Fig. 2. The techniques applied for fluidising the bed are conventional, and a description of the apparatus is given in Table I below.

The sampling tube was designed to take simultaneous samples of solids from the bed at various heights, and was capable of traversing the bed. The concentric tubes were made to fit well. Small openings were cut into the inner and outer tubes so that by rotating the tubes relative to one another, the inner tube opening could be opened or closed. Compartments were made in the inner tube by soldering brass discs at the top and bottom of the rectangular openings. Nine such compartments were made over the height. The handles facilitate rotation, producing an instantaneous sampling effect, all compartments filling at the same time. In practice, this tube proved remarkably effective, each compartment being completely filled with powder. Samples were taken in three positions: (i) at the wall, (ii) at the centre, (iii) mid-way between wall and centre.

Rotameters precalibrated for the existing conditions were used for measuring the air flow.

Pressure taps and manometers were fitted as shown in the flow diagram. The tappings were in the form of annular rings with continuous slots around the periphery. These slots lead to a gallery from which the tube tapping is taken.

Minimum Fluidising Velocity

The fluidising velocity is important in determining both bed classification tendency, and rates of elutriation. These effects have not been examined in the present paper, but it

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* Work submitted for a University of London Ph.D.

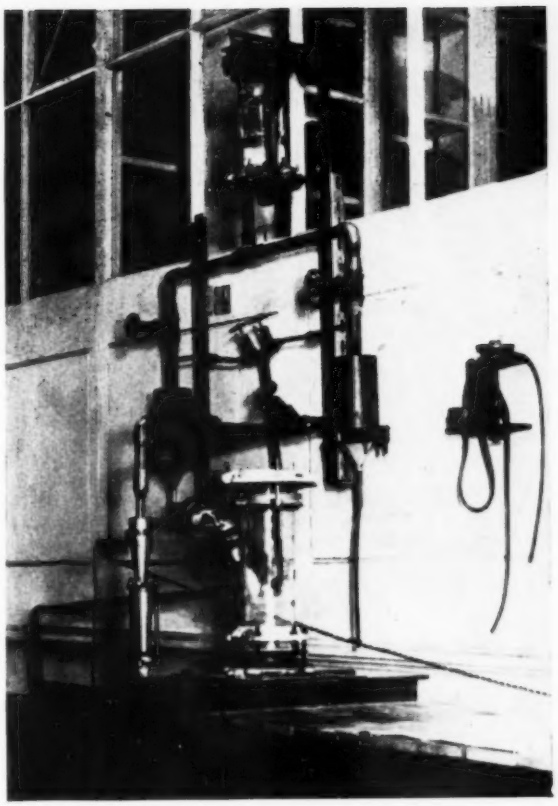

Fig. 1. A view of the upper part of the apparatus shown in Fig. 2, showing the sintered bronze filters and cyclones.

TABLE I

Fluidising Column Main column Column base Column top Top plate Air distributor	 4 in. i.d. × 6 ft. long glass. 4 in. i.d. × 1½ in. i.d. glass reducer. 4 in. i.d. × 1 ft. long glass section with a 45 × 1½ in. offtake to the cyclone. Designed to close the top and carry the sampling tube. 4 in. o.d. × ⅛ in. thick Grade A sintered bronze disc. Annular ring of brass bolted to disc with a rubber sealing ring-glass wall to disc. The whole plate can be raised or lowered by an attached stainless-steel rod to adjust freeboard.
Cyclone	Design based on published data of Stairmand. 2 in. i.d. suitable for air flows 0.1-10 free ft³/m. Rapping device to prevent sticking at the walls. Mains-operated solenoid rapper. Cyclone made of 20-gauge copper sheet internally nickel plated to present a smooth surface. Removes 99 per cent of elutriate from air.
Filters	Sintered bronze Grade 2A in the form of cones. Filtering area 40 in.². Filters all material 2.5 microns.
Sampling Tube	Fig. 4 shows the construction of this sampler. Concentric tubes o.d. ½ in. Each compartment ½ in. × ½ in. high. Nine compartments. The concentric tubes fitted with handles at the top to enable the tubes to be rotated in opposite directions for opening and closing compartments. Sampler bolted to the top plate. This plate contains slots so that the sampler can be moved laterally.
Sampling Tube Frame	Constructed to hold the tube after sampling and withdrawal from the fluidised bed. Enables compartments to be emptied simultaneously into prepared sample bottles.
Air Lift	1 in. i.d. ¼ in. tube attached externally for injecting air into the base of the 1 in. tube. This tube used for emptying the bed by air lift.
Air Elutriation Column	Fig. 6, Part 1, and is a simple glass vessel 4 in. i.d. × 4 ft. long into which the material from the fluidised bed is emptied by air lift. The material is then air elutriated to determine the size distribution of particles.
Air Supply	100 psig reduced to 10 psig. Dried with $CaCl_2$ and Al_2O_3.

will be seen that some results are available incidental to the main work. Fig. 4 gives values for the minimum fluidising velocity for different experiments, and shows how pressure drop varies with air rate. The curves are typical. In Table II are given relative values of actual fluidising velocities to the minimum velocities for the classification and elutriation experiments.

Classification

The segregation of gas from solids, and a simultaneous segregation of fine solids from coarser solids, is an important feature of aggregative fluidisation. Gas bubbles form initially at the distribution plate, and their growth and collapse depend on the rate of segregation of gas from the dense fluidised phase to the bubbles. The segregation of fines is a function of gas velocity, and is opposed by remixing effects due to bed turbulence and consequent bubble collapse. The overall effect of increase of gas velocity is an increase in segregation tendency, resulting in a higher degree of classification of material in the bed, and a more stable bubble phase.

Published work on solids classification in fluidised beds is extremely limited. LEVA[1] carried out research with sand, OSBERG and CHARLESWORTH[2] with Scotchlite beads, PARENT. YAGOL and STEINER[3] noticed a certain amount of classification of material with wide size ranges. Mention of the subject is made by GREGORY.[4] HALL and CRUMLEY,[5] using Fischer-Tropsch catalyst, found marked segregation of particles occurred in the bed. Assuming that the rate of segregation is in the viscous range, MORSE[6] showed that

$$u_0 = \frac{\varepsilon_3^3 \triangle P \cdot g}{5 \cdot a_0^2 \cdot \mu \cdot L_1} \quad \ldots . (1)$$

and that $$\triangle P = L_f(\rho_s - \rho_F)(\varepsilon_2 - \varepsilon_1) \quad \ldots . (2)$$

Eliminating $\triangle P$,

$$u_0 = \frac{L_f (\rho_s - \rho_F)(\varepsilon_2 - \varepsilon_1)}{\mu \cdot a_0^2 \cdot 5 \cdot L_1} g_c \varepsilon_3^3 \quad \ldots . (3)$$

From this equation MORSE concluded that the segregation tendency is self-accelerating, as it depends on $(\varepsilon_2 - \varepsilon_1)$. Segregation tends to be greatest at the bottom of the bed $(u_1{}^2 L_f)$, so that the deeper beds have poorer fluidisation. Higher segregation rates can be expected with denser particles.

A highly segregated bed contains long channels and large masses of slightly separated particles in the dense fluidised phase. The gas passing through the channels carries with it portions of the dense phase, which are then deposited in lower velocity areas at the bed surface. The fluid velocity through the interstices of the dense fluidised phase will also be sufficiently high to suspend heavy particles, and to carry fine particles to the bed surface. At the surface there is a sharp change in gas velocity. Due to this drop in velocity, only a smaller size of particle will be capable of carry-over. All particles varying in size from the largest suspended in the gas flowing in the interstices, to those nearly at the size suitable for elutriation, will be deposited at the surface of the bed. This deposition will produce a surface layer of finer particles which are incapable of elutriation but can be maintained at the surface. This conception is a new one, and the purpose of the classification experiments was partly to demonstrate that this phenomenon occurs.

The methods of sampling of particles from the bed and their subsequent analysis have already been discussed in the present paper and in Part I.

The results of the classification experiments are summarised in Figs. 5, 6, 7, 8 and 9. Details of Run C_4 are given in Table III below, and are typical. Further details are given by GREY[7] and in Table IV.

The results show that a definite concentration gradient exists between the centre of the fluidised bed and the wall in every

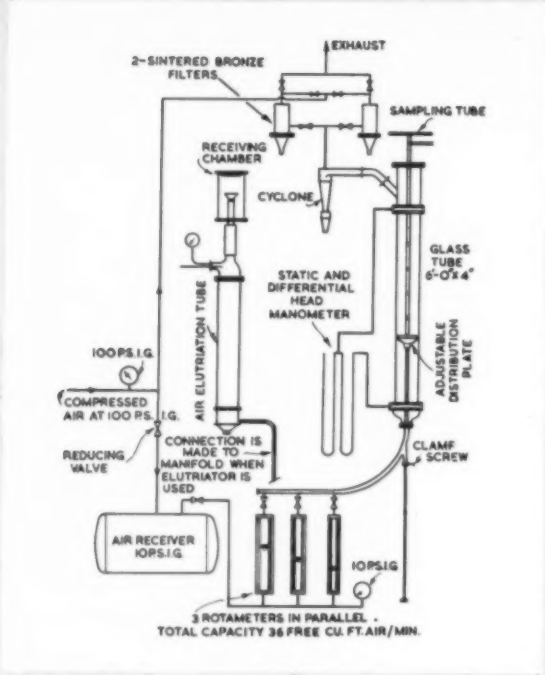

Fig. 2 Flow Diagram of Research Apparatus.

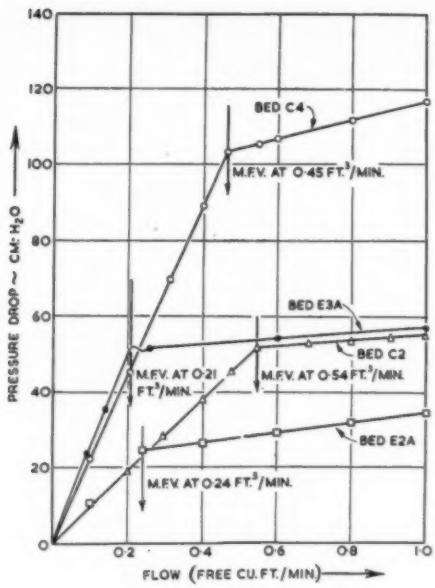

Fig. 4 Typical Pressure Drop Curves. Giving minimum fluidising vely.

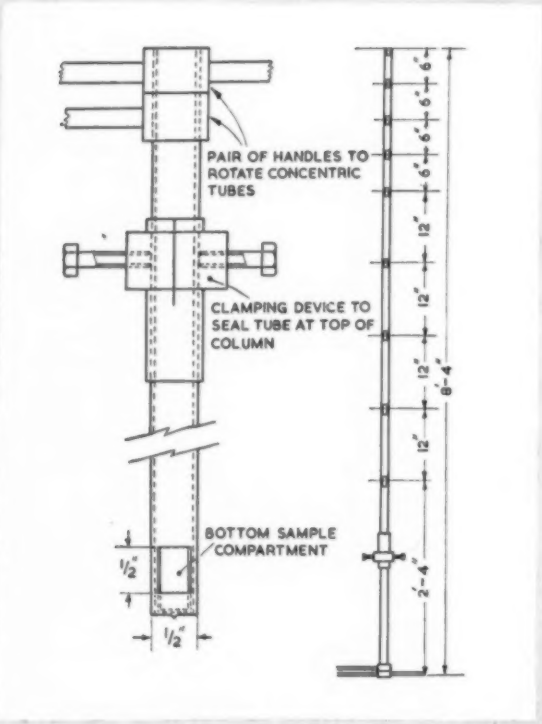
PAIR OF HANDLES TO ROTATE CONCENTRIC TUBES
CLAMPING DEVICE TO SEAL TUBE AT TOP OF COLUMN
BOTTOM SAMPLE COMPARTMENT
8'-4"
2'-4"

Fig. 3 Concentric Tube Bed Sampler. Diagram showing spacing of sampling compartments.

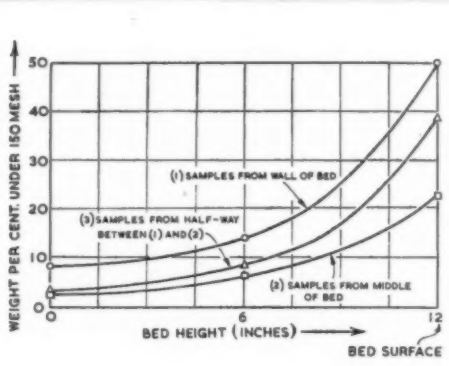
WEIGHT PER CENT. UNDER ISO MESH
(1) SAMPLES FROM WALL OF BED
(3) SAMPLES FROM HALF-WAY BETWEEN (1) AND (2)
(2) SAMPLES FROM MIDDLE OF BED
BED HEIGHT (INCHES)
BED SURFACE

Fig. 5 Classification Run C1. Nominal Fines Concentration : 2% Bed Height: 12 inches. Air Flow rate: 1.0 free cu. ft./min.

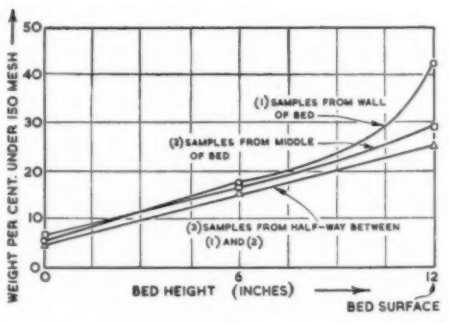
WEIGHT PER CENT. UNDER ISO MESH
(1) SAMPLES FROM WALL OF BED
(2) SAMPLES FROM MIDDLE OF BED
(3) SAMPLES FROM HALF-WAY BETWEEN (1) AND (2)
BED HEIGHT (INCHES)
BED SURFACE

Fig. 6 Classification Run C2. Nominal Fines Concentration: 5% Bed Height: 12 inches. Air Flow rate: 1.0 free cu. ft./min.

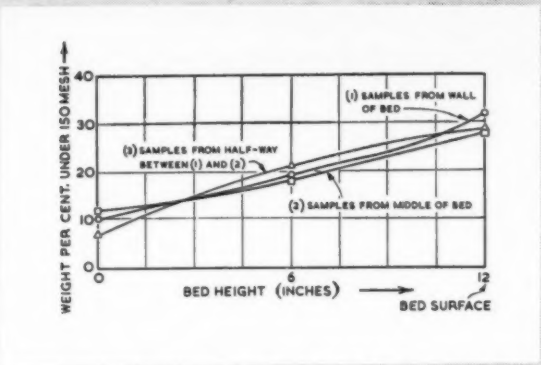
WEIGHT PER CENT. UNDER 150 MESH
(1) SAMPLES FROM WALL OF BED
(3) SAMPLES FROM HALF-WAY BETWEEN (1) AND (2)
(2) SAMPLES FROM MIDDLE OF BED
BED HEIGHT (INCHES)
BED SURFACE

Fig. 7 *Classification Run C3. Nominal Fines Concentration:* **10%** *Bed Height:* **12** *inches. Air Flow Rate:* **1.0** *free cu. ft./min.*

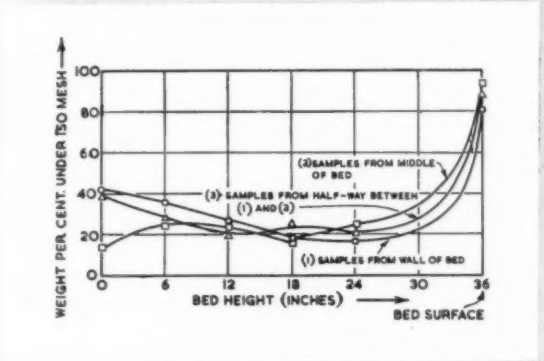
WEIGHT PER CENT. UNDER 150 MESH
(2) SAMPLES FROM MIDDLE OF BED
(3) SAMPLES FROM HALF-WAY BETWEEN (1) AND (2)
(1) SAMPLES FROM WALL OF BED
BED HEIGHT (INCHES)
BED SURFACE

Fig. 8 *Classification Run C4. Nominal Fines Concentration:* **5%** *Bed Height:* **36** *inches. Air Flow rate:* **1.0** *free cu. ft./min.*

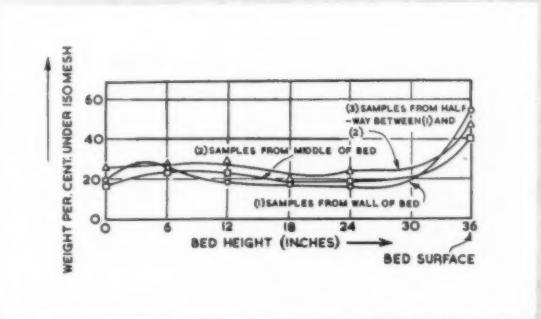
WEIGHT PER. CENT. UNDER 150 MESH
(3) SAMPLES FROM HALF-WAY BETWEEN (1) AND (2)
(2) SAMPLES FROM MIDDLE OF BED
(1) SAMPLES FROM WALL OF BED
BED HEIGHT (INCHES)
BED SURFACE

Fig. 9 *Classification Run C5. Nominal Fines Concentration:* **10%** *Bed Height:* **36** *inches. Air Flow rate:* **1.0** *free cu. ft./min.*

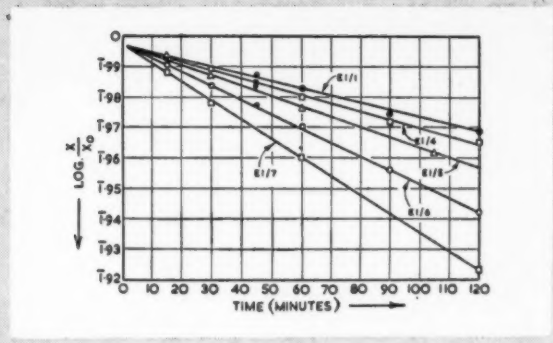

Fig. 10 *Elutriation Runs—E1/1—7. Plot of Log* $\frac{x}{x_0}$ *vs. Time (Min.)*

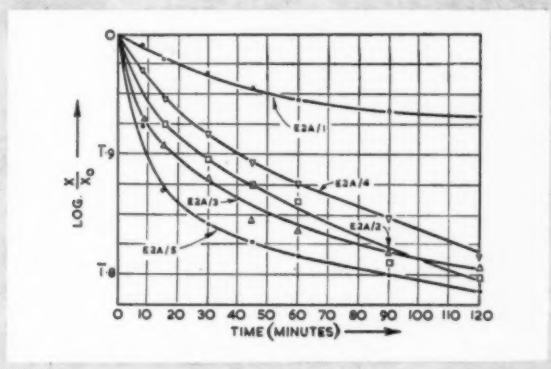

Fig. 11 *Elutriation Runs—E2A/1—5. Plot of Log* $\frac{x}{x_0}$ *vs. Time (Min.)*

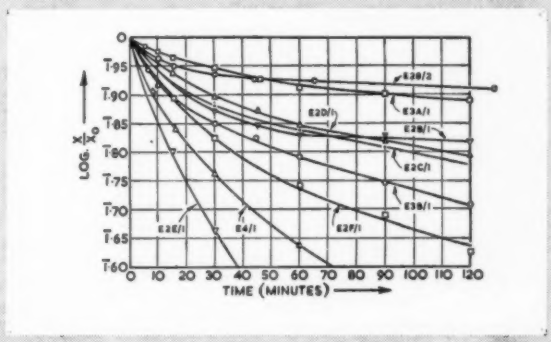

Fig. 12 *Elutriation Runs E28/1 to E4/1.*

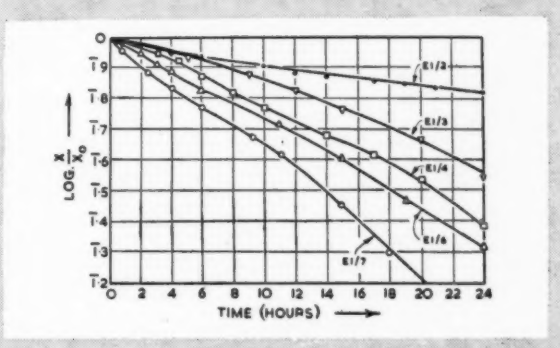

Fig. 13 *Elutriation Runs E1/2—7. Plot of Log* $\frac{x}{x_0}$ *vs. Time (Min.)*

case. The gradient is dependent on the initial fines concentration and the bed height. This is also true for the surface concentration effect. The concentration of fines in a zone near the surface of the bed is evident in all cases, but the deeper the bed the more pronounced it becomes. For example, Run C_4 shows a rapid increase in fines concentration in a region 6 in. from the top of the 36-in. bed. It is doubtful if a correlation is possible at the moment between fines concentration, bed height, air velocity and initial fines concentration. The results need to be extended.

Elutriation

Many attempts have been made to correlate experimental elutriation rates by the equation:

$$X = X_0 \cdot e^{-k\theta} \qquad \ldots . (4)$$

This equation was used by LEVA.[8]

A plot of log X/X_0 v . θ should give a straight line if the experimental results satisfy the equation. However, agreement with the equation can only be achieved with perfect mixing in the bed. Published results of LEVA,[1] OSBERG and CHARLESWORTH[2] and others show marked deviation from ideal conditions, either as sharp breakpoints or as steady deviation over the whole range. It would suggest that the mixing of solids in the bed is not perfect. Even so, the approximate slopes of the curves obtained have been used to evaluate the elutriation constant k, which has then been used to relate gas velocity and the fines particle size. Taking the slope in this way results in considerable error. In many cases the errors are due to air inclusions in the glass beads used. The technique for density separation of the feed material for the bed has been described in Part I, and it should exclude errors due to these effects.

From the experiments described above on classification of particles within the bed, it would appear that near the surface of the bed exists a zone of fine particles. It may be expected that this zone should have an important effect on elutriation rates, inasmuch as the layer offers a resistance to the transfer of fines into the escaping air stream. This obstruction of the normal transfer of material will depend upon the quantity of fines remaining in the bed, and will decrease with time. The rate of elutriation from the bed may be expressed by the equation:

$$-\frac{dX}{d\theta} \propto X \cdot e^{aX} \qquad \ldots . (5)$$

Expanding e^{aX} and approximating:

$$e^{aX} = 1 + aX \qquad \ldots . (6)$$

Substitution now gives:

$$-\frac{dX}{d\theta} = X(1 + aX) \qquad \ldots . (7)$$

Rearranging and integrating by parts:

$$\log \frac{X}{1 + aX} = -k\theta + c \qquad \ldots . (8)$$

Taking limits $\theta = \theta$ $X = X_0$: $\theta = \theta$ $X = X_0$, we have finally:

$$\frac{X}{1 + aX} = \frac{X_0}{1 + aX_0} \cdot e^{-k\theta} \qquad \ldots . (9)$$

This latter equation correlates experimental results at the beginning of the elutriation period much more successfully than does the simpler equation used by LEVA.

Details of the elutriation experiments using glass ballotini are given in Tables V and in Figs. 10 to 15.

Experimental results obtained with beds of high L/D ratio, and a considerable difference between the smallest and largest particles, sometimes show an initial linear plot. The slope of the line is then taken to be the elutriation velocity. This is illustrated in Figs. 10 and 13. However, the general case gives a curve for the initial period of 1 to

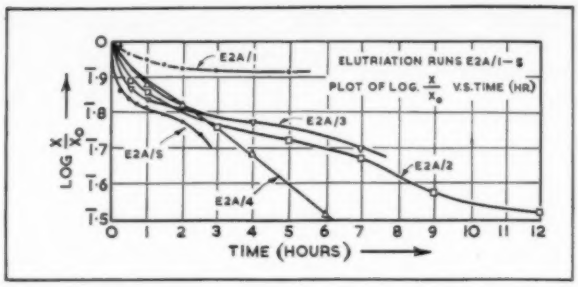

Fig. 14. Elutriation Runs E2A/1—5. Plot of Log $\frac{X}{X_0}$ vs. Time (Hr.)

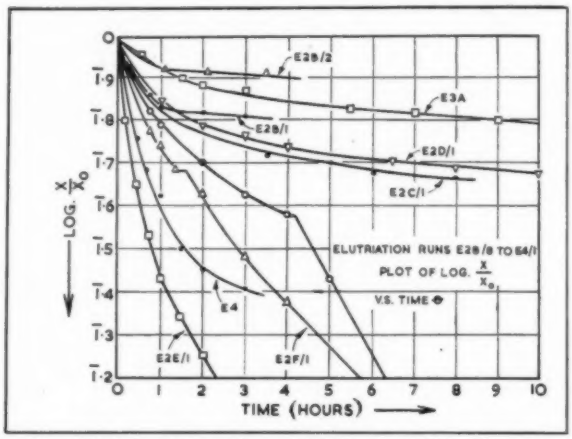

Fig. 15. Elutriation Runs E2B/1. to E4/1. Plot of Log $\frac{X}{X_0}$ vs. Time (Hr.)

TABLE II

Experiment	Bed Height in.	Actual Air Velocity cu ft/min	Min Fluidising Velocity cu ft/min
C 4	36	1	0.45
C 2	12	1	0.54
E 3A	6	4	0.21
E 2A	6	3	0.24

TABLE III—Details of Run C 4

Initial conc.: 5% Grade 15 ballotini (fines). Balance Grade 11
Bed Height: 36 in.
Air flow: 1.0 free cu. ft/min.
Pressure drop: 14.8 cm Hg.
Air temperature: 15°C.

Height in.	Sieving Result gm	Sampling results (weights in gm.) Tube Location: Middle	Half-way	Wall	
0	under 150 M	0.2100	0.5058	0.5643	
	over 150 M	1.1305	0.7664	0.8194	
	% under 150 M	15.65%	39.7%		40.75%
6	under 150 M	0.3249	0.3454	0.4622	
	over 150 M	0.9962	0.9452	0.8659	
	% under 150 M	24.6%	26.7%		34.8%
12	under 150 M	0.3375	0.2757	0.8659	
	over 150 M	0.9264	1.1042	0.3672	
	% under 150 M	26.7%	20.0%		26.8%
18	under 150 M	0.2334	0.2695	0.2360	
	over 150 M	1.1085	0.7809	1.0793	
	% under 150 M	17.4%	25.65%		18.0%
24	under 150 M	0.2702	0.2706	0.2287	
	over 150 M	0.9554	1.0530	1.1697	
	% under 150 M	22.07%	22.45%		16.4%
36	under 150 M	0.8073	0.7268	0.6873	
	over 150 M	0.0480	0.0926	0.1636	
	% under 150 M	94.4%	88.8%		81.0%

TABLE IV—Key to Classification Runs

Run	C_1	C_2	C_3	C_4	C_5
Initial conc. fines: Gr. 15 / Gr. 11	2% / 98%	5% / 95%	10% / 90%	5% / 95%	10% / 90%
Bed height, in.	12	12	12	36	36
Air flow rate free, cu. ft/min	1.0	1.0	1.0	1.0	1.0
Pressure drop, cm Hg.	8.40	8.75	9.05	14.8	15.45
Air temp., °C.	15.2	14.3	14.8	15.0	16.5
Total bed weight gm	3,560	3,673	3,876	10,680	11,273

TABLE V

Run	Initial conc. Gr. 15	Initial conc. Gr. 11	Bed ht. in.	Air rate cu. ft/min	Press. drop cm Hg
E1/1	10%	90%	36	1.0	15.10
E1/2	10%	90%	36	1.5	15.85
E1/3	10%	90%	36	2.0	13.50
E1/4	10%	90%	36	2.5	14.50
E1/5	10%	90%	36	3.0	16.00
E1/6	10%	90%	36	4.0	17.20
E1/7	10%	90%	36	5.0	16.60
	Gr. 15	Gr. 13			
E2A/1	2%	98%	6	3.0	16.00
E2A/2	2%	98%	6	4.0	21.40
E2A/3	2%	98%	6	5.0	24.70
E2A/4	2%	98%	6	6.0	28.75
E2A/5	2%	98%	6	6.5	30.95
E2B/1	5%	95%	6	4.0	20.70
E2B/2	5%	95%	6	5.0	20.70
E2C/1	10%	90%	6	4.0	21.00
E2D/1	20%	80%	6	4.0	22.20
E2E/1	2%	98%	12	4.0	26.50
E2F/1	2%	98%	18	4.0	31.70
	Gr. 16	Gr. 13			
E3A/1	2%	98%	6	4.0	29.40
	Gr. 16	Gr. 14			
E3B/1	2%	98%	6	4.0	28.20
	Gr. 15	Gr. 11			
E4/1	2%	98%	6	4.0	28.35

TABLE VI

$$\frac{X}{1+aX} = \frac{X_0}{1+aX_0}\, e^{-k\theta}$$

Run	a	k
E2B/1	−1.536	−1.887
E2E/1	3.88	0.435
E2D/1	−1.665	−1.106
E2F/1	−2.596	−0.740
E3A/1	−1.297	−1.240
E3B/1	−1.857	−1.262

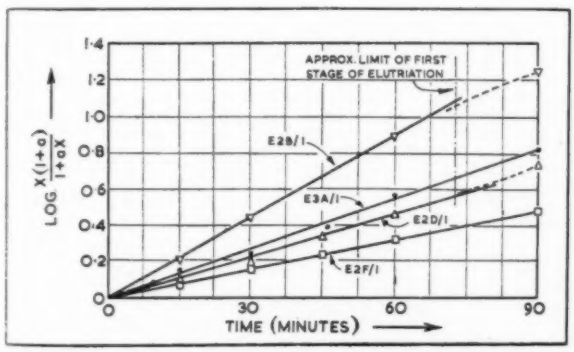

Fig. 16. Correlation of Experimental Results for Elutriation.

2 hr as shown in Figs. 11 and 12. After the initial period a change occurs as the quantity of fine material still present in the bed is reduced to a certain low level. In this region the relationship given by $X = X_0 \cdot e^{-k\theta}$ holds. A plot over this extended period is shown in Figs. 14 and 15. The break-point mentioned by LEVA is evident, being sharper in some cases than others. Fig. 16 shows a plot of log $(X(1 + a)/1 + aX)$ v. θ for the case where X_0 is taken as unity. The runs referred to have a marked curvature in the initial period as shown in Fig. 15. It is seen that the results are well correlated by Equation (9). Values of a and k can be obtained by solution of simultaneous equations. Some values are given in Table 6. An attempt was made to relate the values of a and k to the characteristics of the bed, but the problem is so complex that further experimental work is necessary before any correlation can be achieved.

Equation (9) is successful in correlating experimental results in the early period of elutriation. The importance of this correlation cannot be over-emphasised, since a continuously operating bed could be maintained in this condition. The a factor is complicated, involving classification in the bed. Deviation from the simple Equation (1) is due to classification in the bed, and the formation of a layer of fines at the surface, so reducing the elutriation rate. The change in the conditions for elutriation after a certain time, that is at the break-point, is not unexpected. Flow characteristics in fluidised beds are extremely sensitive to losses of small quantities of fines from the bed. Around the break-point there is a marked change in the nature of the surface layers, which allows elutriation to proceed at a rate sensibly unaffected by the surface resistance.

Summary

An apparatus has been described for investigating the classification and elutriation tendencies in a fluidised bed. The results quoted in the present paper are restricted to glass ballotini. A method of taking samples from the bed simultaneously at different heights proved to be most successful. Samples were analysed by the methods described in Part I.

A lateral concentration gradient of particles was shown to exist from the centre of the bed to the wall. This gradient is dependent on the initial fines concentration and the bed height. In addition, there is a concentration of fines near the surface of the bed, the depth of this fines zone increasing with the bed depth. In all cases, concentration gradients were shown to exist, and the beds were segregated.

The existence of two conditions for elutriation observed by other workers was confirmed. In the general case a plot of log X/X_0 v. θ shows a marked curvature up to 90 to 120 min after elutriation begins. After this period, the elutriation conforms to the simple expression $X = X_0 e^{-k\theta}$. The break-point is more pronounced in some cases than others. An equation like (9) satisfactorily correlates the X and θ values in the initial period. The factor a depends on the bed classification, and k is the elutriation constant. The reason for the anomalous initial condition is the influence of the fines zone at the bed surface on elutriation. Its effect becomes less apparent in batch operation as the experiment proceeds, due to an overall loss of fines from the bed. Its importance in continuous operation with a feed material containing a constant concentration of fines is evident.

To relate all the variables requires many more experiments, which preferably should be statistically designed. However, the present work, in demonstrating the significance of classification and elutriation, clearly points the way.

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ECONOMY IN DISTILLATION EQUIPMENT DESIGN

Simple rules are given for selecting economical plate thicknesses for column shells, and for determining the cost of shells constructed from mild steel. From the latter costs it is possible to arrive at the corresponding costs for shells in monel, stainless steel and clad materials. Costs of bubble-cap trays are also provided from which the total cost of a tower can be calculated; by means of factors, the costs of towers with other types of tray, such as the Kittel and Flexitray, may be estimated

by M. STOGENS

DISTILLATION columns are among the most expensive pieces of equipment to be found in chemical plants and in petroleum refineries. Their form of construction fits them for other unit operations, apart from distillation, such as absorption and extraction, and they are also used as continuous reactors for such processes as alkylation, platforming, chlorination, hydrodesulphurising (hydrofining) and polymerisation.

Common experience of the cost of such towers, based on material plus labour only, is that for complex hydrocarbon and organic conversion plants the costs are rather smaller percentages of total investment than in the case of simple separation units. The percentage cost may range from 3 to more than 30 per cent, with the average lying between 5 and 15 per cent.

There is thus good reason for seeking economy in the construction of such columns. This presupposes that the process design has been properly considered, and that the equipment has been provided with adequate but not overdesigned separating power.

Economy in Mechanical Features

At this stage it would be useful to give a few rules of thumb for determining the minimum wall thickness of vessels greater than 50 ft in length. Taking a column of 10 ft in diameter, every 20 ft of height above 50 ft requires an additional plate thickness of $\frac{1}{16}$ in. This gives the following plate thicknesses:

Height in ft	*Minimum plate thickness in inches*
50	7/16
70	$8/16 = \frac{1}{2}$ in.
90	9/16
110	$10/16 = \frac{5}{8}$ in.
130	11/16
150	$12/16 = \frac{3}{4}$ in.

These figures must, of course, be used with judgment, particularly as economic design requires that the bottom sections are heavier than those of the top. The rule may therefore be modified by stating that, for an atmospheric column 150 ft in height, the lowermost 40 ft would have a plate thickness of 1 in., the intermediate 50 ft of $\frac{3}{4}$ in. thickness and the uppermost section of 60 ft of $\frac{11}{16}$ in. thickness.

When a column has a large diameter to length ratio, plate thicknesses increase, partly in order to provide rigidity. Smaller plate thicknesses are permissible if the shells are X-rayed and stress relieved. X-raying adds approximately 6 per cent and stress-relieving 8 per cent to the purchase price of the vessel. Sometimes the additional cost of this kind of inspection and treatment results in an overall saving in first cost.

When, however, large plate thicknesses are demanded, as is the case with high-pressure process equipment, X-ray inspection may not be reliable; above 3 in. thickness X-raying is likely to miss flaws in a joint. In such cases the ultrasonic test is a better form of inspection.

It is worth noting that a slender column is better able to withstand internal than external pressure, a point which must be borne in mind if the vessel is to be used for vacuum. It would be useless, for example, to design a column for 15 psig internal pressure and expect it to function satisfactorily at full vacuum. The best that could be expected in such a case would be the ability to withstand a pressure no greater than 5 in. Hg. It is not always necessary to resort to heavy thickness of plate in such cases, since, by using slightly heavier tray support rings or stiffening rings, a thinner shell material can be permitted. A useful rule in this connection for calculating the weight of a cylindrical shell is: outside diameter in inches multiplied by the number of tenths of an inch plate thickness gives the approximate weight in lb/ft. Thus a cylinder of 100 in. diameter, wall thickness 0.5 in., weighs approximately $100 \times 5 = 500$ lb/ft.

Sometimes appreciable saving in cost can be achieved by using a material of higher tensile strength, and the higher price of the material may be more than compensated by its reduced weight. There are times, however, when it is more economical to use heavier plate, and examples have been known of columns with shells of such a thickness that reinforcement was required at the larger openings, the cost of the reinforcements being enough to offset the apparent economy obtained by using small plate thickness. The use of the next heavier plate size was sufficient to eliminate the need for the reinforcing and with a reduced cost of construction.

Parts of specifications for vessels which can lead to unnecessarily high cost are tolerances. They should be limited to those components which are necessary for the successful operation of the column. Items which offer possibilities for economy are nozzles and flanges, and this is best effected if the fabricators are allowed to quote for their standard designs, because they can frequently make to their own

designs more cheaply than they can buy commercial fittings which are often of the forged type.

Where the conditions are corrosive, special materials of construction will have to be considered, and one may have the choice, for example, of a construction in stainless steel or in a clad material. In making the choice, it must be borne in mind that there will be an economic break point. As a general rule, it may be stated that since the normal minimum total thickness of clad plate is $\frac{3}{16}$ in., little or no saving can be made if the required shell thickness is under $\frac{1}{4}$ in.; and below the normal thickness of $\frac{3}{16}$ in. for clad plate its cost will be greater. On the other hand, for thicker plate the cost may be reduced by as much as 20 per cent through the use of clad material.

Distillation Column Costs

Fig. 2 gives prices of distillation columns inclusive of shell, ends, supports, nozzles, manholes, but excluding trays, for different thicknesses of shell. This figure shows that a column 10 ft in diameter, $\frac{5}{16}$ in. plate thickness, 100 ft total length cross ends, will cost 100 × £100 = £10,000.

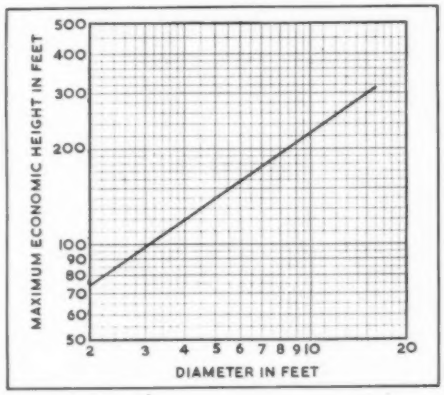

Fig. 1. Economic column heights for various diameters.

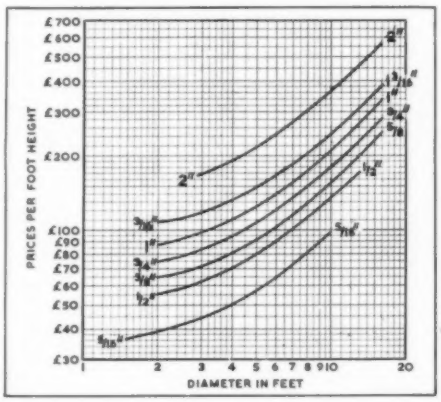

Fig. 2. Prices of mild steel distillation columns—shell including heads, supporting nozzles, manways—per foot height (f.a.g.) excl. trays.

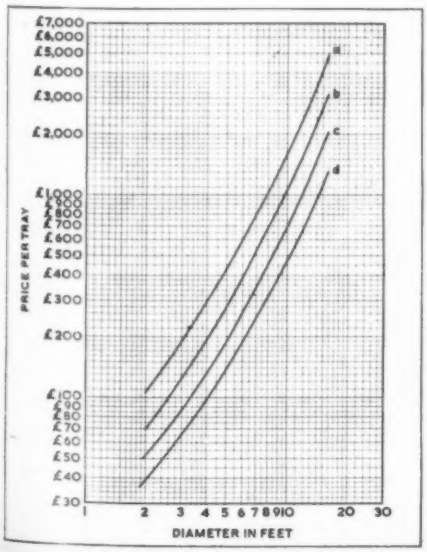

Fig. 3. Prices of bubble-cap trays.
a = *monel;*
b = 17/10/2.5 *Mo stainless steel;*
c = 12/14 *Cr steel;*
d = *mild steel.*

For stainless-steel and monel constructions the following conversion factors may be used with mild steel as unity.

CONVERSION FACTORS

Material		When taken into account the higher strength of stainless steel	When plate thickness is equal to mild steel	When using cladding materials
	AISI* grade			
	410	2.4–3	2.8–3.5	2.2–2.8
	304	2.7–3.5	3.4–4.5	2.3–3
	316	3.0–3.75	3.6–5	2.6–3.5
monel		3.8–5	4.7–6.5	3.0–4.0

The largest factors apply to the largest size of column. Thus, the larger the column, the steeper the increase in plate weight. Likewise, the cost of the material. Labour costs, however, do not increase proportionately.

The prices of bubble-cap trays constructed in several materials are given in Fig. 3, and the following factors are given for converting to other types of tray:

Flexitrays	0.8
Kittel trays	0.6
Shower deck trays	0.5
Disc and doughnut trays	0.6
Bar stock grid trays	0.6
Slotted-type grid trays	0.75
Ripple trays	0.65

The Cost of Complete Distillation Units

To obtain the total cost of an erected column requires the addition of a number of other costs to the purchase price. Thus the following percentages of the purchase price must be added for the stated items:

	%
Pipelines	70-60
Instruments	10-30
Site work	3- 5
Foundations	5-10
Insulation	10-20
Temporary constructions	1- 2
Painting and fire-proofing	3- 5
Electric equipment	3- 5
Piling	0-10

The erection cost of a column can amount to 10 to 30 per cent of its purchase price. As a rule, the general average for a column, complete with ancillary equipment, will be four times the f.o.b. price.

Thus taking the column cost as 100, additional materials may amount to 110, total erection and all indirect costs may come to 110 and 80 respectively.

When, however, stainless steel is the column material of construction, the lower figure should be used, since the steel structure, instruments, erection cost and so on, will be similar to that of a carbon steel column and therefore will form a lower percentage of the total cost.

An approximate rule for determining the cost of a distillation unit complete with all ancillary equipment such as reflux accumulator, top product condenser, reflux pump, feed pump, middle reflux pump and heat exchanger, bottom product cooler, reboiler and connecting pipework, structural steelwork, insulation and the rest is to multiply the f.o.b. price of the column by 10.

As with most preconstruction cost estimating short-cut methods, rules of this type have to be used with circumspection. They require experience of equipment costs in this particular field.

* These alloys have the following compositions:

	C	Si	Mn	Cr	Ni	Mo
AISI 410	0.12	0.75	0.60	12.0 14.0	0.60	
AISI 304	0.08	0.85	2.5	18.0 min.	8.0 min.	
AISI 316	0.08	0.85	2.5	17.0 min.	10.0 min.	2.0 min.

RECENT ADVANCES IN HEAT TRANSFER

PART II

One of the largest events ever to be devoted to this field brought forth papers dealing with such aspects of the subject as heat transfer in the presence of particulate matter, with change of phase, and forced and natural convection. Boiling heat transfer papers touched upon burn-out, film boiling, sub-cooled nucleate boiling, while one paper examined the effect of surface roughness upon pool boiling. Another reported an investigation on boiling at wick-covered surfaces. In the sphere of combined heat and mass transfer a procedure was also described for predicting dehumidification at finned surfaces. Other papers dealt with heat transfer in packed beds and fluidised beds, and with the effect of turbulence promoters

Heat Transfer With Phase Change

PAPERS given in this field, apart from those reported in the January issue of this journal, covered many other sides of the subject; but one only was concerned with the melting of solids. In this paper (No. 4), ALTMAN presented approximate analytical solutions for the region around the peak of the heat flux curve, and he showed that in this region the steady-state solution is close to the actual transient solution.

Boiling, on the other hand, received a great deal of attention. BEATTY, for example (paper 17), analysed and offered an interpretation of the boiling heat transfer curve. He concludes that the "burn-out" point is an optimum resulting from two competing factors, and the transition region is a continuation of the nucleate boiling region with no significant change in mechanism occurring at the burn-out point. Transition boiling, the subject of a paper by BERENSON (paper 18), was considered by him to be an alternation at a given location, of nucleate and unstable film boiling.

In the field of sub-cooled nucleate boiling, the subject of two papers (Nos. 19 and 20), BANKOFF proposed expressions for the quenching heat flux and for the mean amplitude of the velocity fluctuation in the liquid between bubbles and for the critical heat flux region. COLE (paper 21) offers a dimensionless equation relating bubble velocity, bubble diameter and contact angle at break-off.

The partial film boiling region was the object of an experimental study by MCDONOUGH, MILICH and KING (paper 29) who determined the surface flux at 800, 1200 and 2000 psia in a round vertical tube. They presented a correlation covering their own and already-published data. Two other papers dealt with the effect of trace additives (paper 30), and nucleate boiling with aqueous ThO_2 slurries (paper 31). In the latter paper THOMAS reported that the heat flux density at a fixed temperature difference was independent of the slurry concentration. In a related field LUNDE (paper 26) recorrelates heat transfer and pressure drop data by means of a published dynamic model.

The Effect of Surface Roughness

In the same field S. T. HSU and F. W. SCHMIDT presented a paper (60-HT-32) in which they examined the effect of the heat-transfer surface material, its roughness and the heat flux, upon the magnitude of the temperature variation of the heating surface for the pool-boiling of water at atmospheric pressure.

Essentially this is a heat-transfer problem of three-dimensional unsteady-state conduction in the presence of variable film coefficients. The latter were considered a function of time, shape, frequency and other factors effecting the growth of bubbles formed at the heat-transfer surface.

Symbols Used

f = frequency of variations in cycles per hour;
α = thermal diffusivity in ft²/hr;
k = thermal conductivity in Btu/ft hr;
$\Delta T_{av\ sat}$ = temperature difference between heating surface and saturation temperature of water;
q = heat flow, Btu/ft² hr.

The test specimens which these authors used in their experimental boiling apparatus included ground stainless steel, polished stainless steel and polished aluminium rings, varying in surface roughness from 5.2 to 140 micro-inches. The purpose of the work was to obtain a method of comparing the performance of different surfaces for different heat fluxes, materials and surface finishes, as well as to obtain an indication of the maximum temperature variation and the frequency at which variations occurred.

It was found that the maximum average temperature variation could be predicted by the following equation, whose various constants were obtained for different materials according to the table below.

$$\Delta T_{avg\ max} = c[q(f/\alpha)^{\frac{1}{2}}]^{-b}(q\Delta T_{av\ sat}/K)$$

Surface description	*a*	*c*
Aluminium 13 RMS	0.706	41.2
Stainless steel 5.2 RMS	1.030	297.6
Stainless steel 19 RMS	0.630	5.865
Stainless steel 21 RMS	0.688	16.44
Stainless steel 140 RMS	0.920	484.6

The authors concluded that the surface temperature of the heating surface varied during nucleate boiling and the amplitude and frequency of the variations were, in the main, dependent upon heat flux and the surface finish.

On a lower plane, a point worthy of mention is the thermal couple probe which the investigators used for measuring surface temperatures. This consisted of a constantan wire enclosed in a stainless-steel hypodermic needle, the couple being formed by the junction of steel and needle formed by silver soldering the two together.

Burn-out

Burn-out, one of the principal limitations in the design of high specific power equipment, was dealt with in a number of papers. GOLDMAN, FIRSTENBERG and LOMBARDI were concerned with burn-out in turbulent flow, pointing out, early on in their paper (60-HT-34), that existing analytic methods for predicting burn-out have relied upon physical models which have been based on pool-boiling observations. Such analyses correlate pool

* First National Heat Transfer Conference and Exhibit sponsored jointly by the Heat Transfer Divisions of the A.I.Ch.E. and the A.S.M.E., August 1960.

Symbols Used

G_t = total mass flow rate, lb_m/hr-sq ft;
h_{fg} = latent heat of vaporisation, Btu/lb_m;
k_g = film coefficient for mass transfer, fph;
$K_G \equiv k_g/u_g$ = dimensionless mass transfer coefficient;
$s \equiv u_g/u_f$ = axial slip ratio;
u = average velocity at a section, fph;
x = average steam flow quality at a section, weight fraction;
ΦBO = burn-out heat flux, Btu/hr-sq ft.

Subscripts

f = liquid phase;
g = vapour or gas phase.

boiling data well but fail for flowing systems. The authors suggest that the mechanism controlling burn-out in flowing systems, particularly at high Reynolds numbers transport is to be found in eddy diffusion—limited through a steam boundary layer at the heated wall. This idea is applicable to fog-flow and possibly also to low-quality steam and sub-cooled liquid systems.

They consider that burn-out occurs when the liquid mass flow through an annular film postulated to cover the heat transfer area, and from diffusing droplets, is insufficient to maintain the heat flux.

Dealing with fog-flow, they state that their basic equation

$$\Phi_{BO} = K_G s(1 - x)G_t h_{fg}$$

cannot be used readily until more data are available on the mass transfer coefficients and slip. One of the difficulties in calculating mass transfer coefficients is the lack of knowledge of eddy slip.

Previously eddy diffusivity for mass and momentum transfer had been assumed equal, but in the eddy diffusion of liquid droplets the greater inertia of the latter prevents them from following the motion of the carrier fluid exactly. This means that lower values for mass transfer coefficients are obtained than those based on the analogy between mass and momentum transfer in turbulent streams. Experiments are quoted where ratios of eddy diffusivities of mass to momentum transfer of approximately one-third were obtained. Some preliminary comparisons are given for calculated and experimental results, the assumption being made that the actual slip ratio is 1. Mass transfer coefficients are calculated by means of the previous equation, using existing burn-out data. Mass transfer coefficients and friction factors are plotted against Reynolds number to test the validity of the proposed burn-out model; the spread of data, which was expected to be considerable, on account of the over-simplifying assumptions of axial and eddy slip ratios and Schmidt numbers equal to 1, gives an order of magnitude agreement between calculated mass transfer coefficients and single-phase friction factors.

Boiling at Wick-covered Surfaces

Although heat transfer under nucleate boiling conditions is a familiar field, the use of wick-covered surfaces for cooling by evaporation is much more of a novelty. At present the main outlet for this technique appears to be for cooling the surfaces of space vehicles, when the evaporating liquid can be kept in contact with the surface in the absence of a gravitational field. However, it would not be surprising for it to find other uses.

ALLINGHAM and MCENTIRE (60-HT-11) give results of an experimental study of this type of cooling for which they used a 1-in. O.D. horizontal copper tube embedded in a water-saturated ceramic fibre-wick material. They were able to correlate their results for heat fluxes in the range 1000-10,000 Btu/hr ft² by the dimensionless equation:

$$\left(\frac{h}{CG'}\right)\left(\frac{C\mu}{K}\right)^{0.6}\left(\frac{\rho_L\sigma}{P^2}\right)^{0.21} = 0.072\left(\frac{D_e G'}{\mu}\right)^{-0.77}$$

where

$$G' = \frac{Q}{A\varepsilon\lambda}$$

The presence of wick material at a heat-transfer surface was found to depress turbulence near the surface, to increase the effective heat transfer area, and to provide active sites for bubble formation. The net result is higher film coefficients at

Symbols Used

A = area of boiling heat-transfer surface, ft²
C = specific heat of liquid, Btu/lb °F
D_e = dimension parameter, ft = $4r_h$
$G' = \frac{Q}{A\varepsilon\lambda}$ lb/hr ft²
h = boiling film coefficient, Btu/hr ft² °F
K = thermal conductivity of liquid Btu/hr ft °F
Q = heat flow, Btu/hr
r_h = hydraulic radius, ft $\frac{\varepsilon}{A_s}$
ε = porosity factor $(1 - \rho_{wi}/\rho_f)$, dimensionless
λ = latent heat of vaporisation, Btu/lb
μ = viscosity of liquid, lb/hr ft
ρ = density, lb/ft³
σ = surface tension of liquid, lb/ft

Subscripts

L = liquid
s = surface

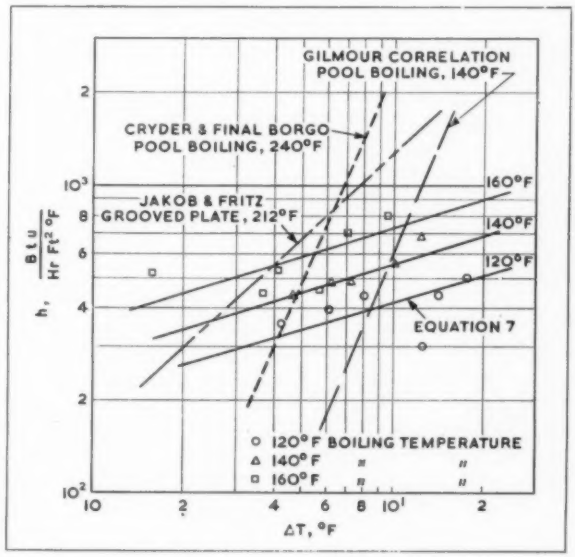

Fig. 1. Comparison of boiling film coefficients for wick boiling and pool boiling (60-*HT*-11).

lower values of heat flux than are found with pool boiling; at high heat fluxes, however, the film coefficients for wick-covered surfaces are less than those for pool boiling. The important parameter for wick boiling is the width of the capillary passages formed by the fibres near the surface.

It should be mentioned that this work was carried out for a single combination of wick material and metal surfaces, so that the effect of changing these variables has still to be discovered.

O. J. MENDLER, A. S. RATHBUN, N. E. VAN HUFF and A. WEISS (60-HT-36) presented the results of a study carried out: (1) to compare experimental natural circulation loop-flow rates with predicted flow rates for water at 800-2000 psia under non-boiling, local boiling and bulk boiling conditions; (2) to compare natural circulation, pressure drop, fluid density in riser section, and heat transfer burn-out data with corresponding forced-circulation data; (3) to obtain information on two-phase exit losses and steam-water slip ratios at low water velocities.

The experiments were carried out with singe rectangular channel test sections. Heat fluxes ranged from 50,000 Btu/hr-sq ft to burn-out with inlet sub-cooling of 20, 70 and 100°F respectively.

The authors concluded that single- and two-phase pressure drop, burn-out heat-flux and riser density measured under natural-circulation operation are no different from those

measured with forced-circulation at the same thermal and fluid flow conditions.

They show that flow fluctuations can occur in two-phase natural-circulation flow which are not present during forced-circulation flow at the same conditions. These flow fluctuations increase at lower inlet sub-cooling and system pressures. Burn-out can occur prematurely as a result of flow fluctuations.

They were able to predict for the loop investigated natural-circulation flow rates within 10 per cent, and pressure drops in sections of the equipment could be predicted to within 15 per cent for qualities up to 65 per cent by means of pressure-drop correlations derived from tests on narrower channels than those they used (0.2 × 1 in. and ¼ × 1 in. cross-section).

Dehumidification at Extended Surfaces

Methods so far devised for predicting heat and mass transfer between moist air and cooled extended surfaces have suffered from several drawbacks. For example, some methods do not make allowance for the effect of surface wetness upon fin efficiency, and others are sensitive to inaccuracies in the determination of the final dry bulb temperature of the air. The purpose of the paper given by WARE and HACHA was to present a method devoid of such short-comings, applicable at the same time over a wide range of temperature and humidity conditions.

The method makes use of heat-transfer data obtained from sensible heat-transfer investigations. Fin efficiency is dependent upon whether the heat transfer surface is wet or dry. In the case of a dry surface, the fin efficiency may be written as:

$$\varphi = \frac{t_{db} - t_m}{t_{db} - t_t}$$

and for a wet surface as:

$$\varphi' = \frac{H - H_m}{H - H_t}$$

Symbols Used

q = total heat transfer rate, Btu/hr;
t = air wet-bulb temperature, °F;
t_m = mean temperature of the fin surface, °F;
t_s = mean temperature of the fin and tube surface, °F;
t_t = temperature at the tube surface, °F;
t_r = refrigerant temperature, °F;
t_{db} = air dry-bulb temperature, °F;
H = enthalpy of air, Btu/lb dry air;
H_m = enthalpy of saturated air at the mean temperature of the fin surface, Btu/lb dry air;
H_s = enthalpy of saturated air at the mean temperature of ?????
H_t = enthalpy of saturated air at the temperature of the tube surface, Btu/lb dry air;
h_a = air heat transfer coefficient, Btu/(hr) (sq ft) (°F);
h_r = refrigerant heat-transfer coefficient, Btu/(hr) (sq ft) (°F);
U = overall heat-transfer coefficient between air and refrigerant, Btu/(hr) (sq ft) (°F);
U' = heat-transfer coefficient between fin and tube surface and refrigerant, Btu/(hr) (sq ft) (°F);
A = total area of fin and tube surface on air side of coil, sq ft;
A_t = area of tube surface on refrigerant side of coil, sq ft;
B = ratio of total air side area to refrigerant side area;
m = slope of straight line on a saturated air temperature-enthalpy curve between air wet bulb temperature and mean temperature of the fin and tube surface, Btu/(lb dry air) (°F);
c_s = humid specific heat of air, Btu/(lb dry air) (°F);
φ = fin efficiency with dry fin surface;
φ' = fin efficiency with wet fin surface;
η, η'' = surface effectiveness under dehumidifying conditions.

The authors show that the slopes of the straight lines on the saturated air temperature vs. enthalpy curve between (a) air wet-bulb temperature and mean temperature of fin and surface, (b) between temperature of tube surface and the mean temperature of fin and tube surface, and (c) the slope at the mean temperature of the fin surface are approximately the same. This assumption simplifies the mathematical treatment and causes only a slight error.

For the overall heat-transfer coefficient they obtain:

$$\frac{1}{U}\,\frac{1}{h_a\,\dfrac{m}{c_s}} + \frac{1-\eta_i}{\eta_i\,h_a\,\dfrac{m}{c_s}} + \frac{B}{h_r}$$

and over an element of cooling surface

$$dq = U(t - t_r)\,dA$$

which on rearranging and integrating yield

$$A = \int_0^q \frac{dq}{U(t - t_r)}$$

The following equation describes the heat transfer between metal surface and refrigerant

$$\frac{h_a}{c_s U'} = \frac{t_s - t_r}{H - H_s}$$

The tube surface temperature (t_s) and the enthalpy (H_s) can be obtained by graphical solution of this equation when values of h_a/c_sU', t_r and t are known. The value of m can then be found from

$$dq = \frac{h_a}{c_s}\,(H - H_s)\,da$$

A preliminary or inaccurate value of m is sufficient to determine the fin and tube resistance accurately. This is done by giving value to h_a/c_sU' in the above equation, which lies between the already calculated upper and lower limits of h_a/c_pU', and then solving for the preliminary value of m. The fin and tube resistance can then be accurately determined.

Surface areas calculated by this procedure are compared by the authors with the areas used in test results. The maximum deviation was −2.5% to +0.4%.

The work presented is to be further simplified in a later paper in preparation by the authors.

Pool-boiling in Low Gravity Fields

The interest in heat transfer under reduced gravity conditions was reflected in a paper, also in the boiling heat-transfer field, given by USISKIN and SIEGEL (60-HT-10) on the effect of reduced and zero gravity upon pool-boiling, an area of the subject for which there is very little experimental data. To stress its importance the authors pointed to a number of heat-transfer processes such as free convection, condensation and boiling, which are, in some degree, influenced by gravitational force, so that theoretical expressions containing gravity as a parameter for these heat-transfer processes must be extrapolated for calculations relating to reduced gravitational fields.

The authors therefore set themselves the goal of providing quantitative information on the effect of reduced gravity upon boiling heat transfer and bubble dynamics. The description of the apparatus and technique, which included high-speed photographic observation of nucleate boiling régime, and the use of a number of different electrically heated elements such as stainless-steel tubing, nickel and platinum ribbons in the experiments was followed by a discussion of the results.

Their proper interpretation required consideration of the transient burn-out process, and the theory which predicts that burn-out flux varies as the quarter power of gravity represents the lower limit for the data. The speed of bubble rise was shown to decrease with reduced gravity, and the bubble diameters at the time of detaching from the heated surfaces were found to vary as the 1/3.5 power of gravity.

Heat Transfer in Natural and Forced Convection

The papers falling within the category were many and varied. HELLERUM and CHURCHILL (paper 12), for example, produced methods for determining the minimum number of dimensionless groups and so far reducing the number of independent variables in heat transfer equations, which they illustrate by reference to natural convection heat transfer from a vertical wall. ACRIVOS (paper 13) analysed laminar natural convection heat transfer to

non-Newtonian fluids and obtained exact solutions for the boundary layer equations for fluids of Prandtl number greater than 10.

For the three distinct régimes of natural convection—mitial (or creeping), laminar and turbulent—O'TOOLE and SILVERTON (paper 12) put forward equations which apply to gases and Newtonian liquids, including liquid metals. One notable observation in a paper on natural convection heat transfer near the critical point was a new régime at very high Rayleigh numbers. In this paper (No. 28), BONILLAS noted that for heat transfer in the critical and super-critical regions the usual correlations for turbulent natural convection held good.

A heat-transfer process occurring in many types of equipment is transient natural convection from vertical elements, a process which B. GEBHART analyses by means of an integral method (paper 60-HT-33). He considers that the majority of such processes encountered in practice are better approximated by specifying an energy generation rate in the solid element than by specifying a surface temperature condition. He considers the case in which an element immersed in an infinite bath of fluid at rest suddenly undergoes a dissipation or absorption of internal enegry. In general, the rate at which this energy is dissipated is considered to be a function of time. By means of an energy balance for the immersed element, an energy balance for the fluid and a forced momentum balance for the fluid, he derives differential equations which relate the average surface temperature and time for heating or cooling such vertical elements. The equations given apply to laminar flow for all fluids. In them the important dependent variable is the instantaneous temperature rise parameter which depends upon a generalised time. Two parameters only are included: the Prandtl number and the storage capacity of the element.

The equations are solved for the extreme case of a vertical plate of negligible thermal capacity subjected to a step in flux at its surface. For fluids of Prandtl numbers in the range 0.1 to 1000, the results are shown to be practically independent of the Prandtl number. Simple one-dimensional transient behaviour is followed for approximately one-fifth of the transient with a subsequent rapid approach to the asymptotic value. No overshoot is shown for average surface temperature.

Heat Transfer in the Presence of Solid Particles

In this field, a number of papers were devoted to heat transfer occurring in the presence of solid particles either in a fixed position relative to that of the fluid participating in the heat-transfer process, or in motion.

In this grouping of papers, BADDOUR and YOON (paper 7) gave correlations for the effective radial conductivity near the containing walls of packed beds, and in the remainder of such beds the mechanism of the solid-fluid-solid series was shown to be virtually independent of Reynolds number. MICKLEY, FAIRBANKS and HAWTHORN (paper 8) put to the test the assumption of unsteady-state conduction with packets of quiescent solids, in fluid bed heat transfer. They show that this assumption, combined with observed frequency of fluctuations, leads to good predictions of heat transfer from a tube placed in the centre of a fluidised bed. One of the main features of another paper in this field, given by HOLT (paper 10), was a series of equations useful for predicting the performance and size of equipment used for heat processing by means of fluidised beds.

Finally, the literature dealing with the subject of particle heat transfer in packed and moving beds was reviewed by BOWERS and REINTJES (paper 10), who evolved working equations covering a range of conditions, including gas temperatures in the range 100-1500°F, particle diameters of 15/16 to 1½ in. and gas mass rates of 60-1200 lb/hr ft².

The main advantage of fluid-solid heat transfer systems lies in the higher rates of heat transfer which they produce for a given surface temperature. It has been known for some time that one reason for this is the radiation effect arising from the presence of the solid particles. TIEN (paper 60-H, T-23) analyses heat transfer by a fluids-solids mixture passing in turbulent flow in a pipe; his work was carried out at temperatures of less than 1000°F.

The analysis makes a number of assumptions, such as the solid particles are small enough and have large enough thermal conductivity as to have a uniform temperature field throughout a particle. The particles are also considered to be so finely dispersed that they have a negligible effect upon the velocity distribution of fluid flow.

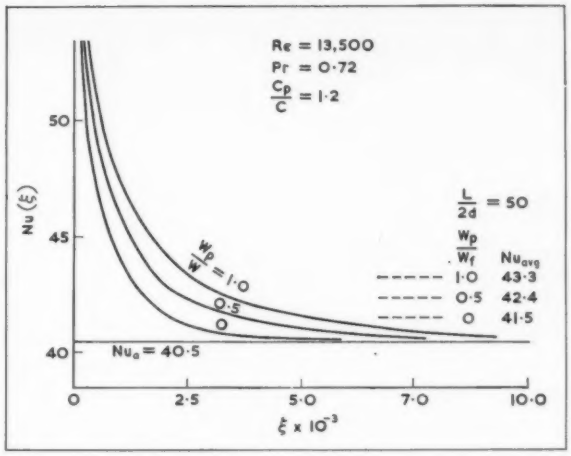

Fig. 2. Variation of Nusselt number local with axial distance for different solid:fluid ratios for twice the Reynolds number of Fig. 1.

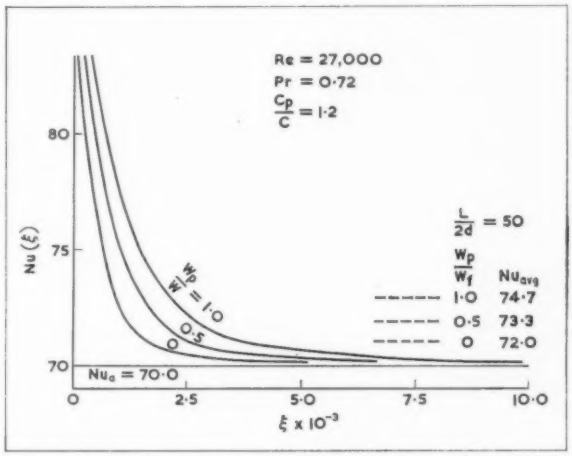

Fig. 3. Variation of Nusselt number local with axial distance for different solid:fluid ratios for the given Reynolds numbers and fluid properties.

Symbols Used

Nu_a = fully developed Nusselt number, dimensionless;
C_p = sp. ht. of solid particle, Btu/lb °F;
C_f = sp. ht. at constant pressure of fluid;
W_p = mass flow of solid particles, lb/sec ft²;
W_f = mass flow of fluid, lb/sec ft²;
$\beta_5 = \left(\frac{C_p W_p}{C_f W_f}\right)$ dimensionless;
D = pipe diameter, ft;
Pr = Prandtl number, dimensionless;
Re = Reynolds number, $Du_{avg}\rho/\mu$, dimensionless;
u_{avg} = average bulk velocity in pipe, fps.
λ_n^2 = eigenvalues, dimensionless;
$\bar{\lambda}_n^2 = (1 + \beta_5)\lambda_n^2$, dimensionless;
$\xi = \left(\frac{2x}{\mathrm{RePr}D}\right)$ dimensionless;

This is not the case when the loading ratio is high, but is valid when the ratio is less or equal to 1.

The effect of particle concentration is to flatten the temperature profile and therefore to increase the heat transfer. For the case of uniform wall temperature, the following equation is given

$$\mathrm{Nu}(\xi) = \frac{\sum_n A_n \exp(-\lambda_n^2 \xi)}{\sum_n \frac{A_n \exp(-\lambda_n^2 \xi)}{\lambda_n^2 (1+\beta_5)}}$$

Far downstream from the thermal entrance all the terms but the first in this equation become negligible, so that it becomes

$$\mathrm{Nu}_a = (\tfrac{1}{2})(1+\beta_5)\lambda_0^2 = (\tfrac{1}{2})\overline{\lambda}_0^2$$

This implies that the asymptotic Nusselt numbers for uniform wall temperatures are identical for two- and single-phase systems. Thus far downstream from the tube entrance solid particles have a negligible effect upon heat transfer.

Figs. 2 and 3 show variations of local Nusselt number with axial distance for different solid to fluid ratios.

The paucity of data on the effect of turbulence upon the local heat transfer from spheres prompted the work reported in the paper of SHORT, BROWN and SAGE. They measured the temperature distribution in a turbulent air stream near an electrically heated silver sphere of 0.5 in. diameter placed downstream of a perforated plate grid.

The air stream velocity ranged from 4-16 pps, and for each of the velocities investigated the conditions of flow in the wake of the grid were represented by a parameter termed the root mean square longitudinal fluctuating velocity, which in the experiments was varied from 0.013-0.15. For a Reynolds number of 3600 and at an apparent turbulence level of 0.013, the local transport around the sphere varied by a factor of 8. When the apparent turbulence level was increased to 0.15, the local heat transfer showed a five-fold variation and the overall heat transfer increased by 20 per cent.

Apart from the technique which these authors used—it included temperature measurements carried out with 0.0003-in. Pt-Rh thermocouple—a number of interesting points emerge.

For example, increase in the level of turbulence produced an increase in average Nusselt number, but in the front half of the hemisphere an increase in level produced a decrease in the relative local heat transfer, whereas in the near half increase in level increased the transfer.

Heat transfer by forced convection from spheres to fluids was the subject of another paper which described an experimental investigation upon an isothermal sphere made of copper located in a stream of water. The authors, VIET and LEPPERT (60-HT-5), heated the sphere by means of a single-turn cylindrical induction coil which surrounded the 2-in. glass pipe in which the sphere was situated.

The correlation obtained allows for variation in properties across the boundary layer by means of a viscosity ratio term resembling that of SIEDER and TATE. The authors put forward an equation for the average heat-transfer coefficient from a sphere to water in forced convection, in the range of Reynolds numbers 50-300,000.

$$N_{\mathrm{Nu}} \cdot N_{\mathrm{Pr}}^{-0.3}(\mu_w/\mu)^{0.25} = 1.2 + 0.53 N_{\mathrm{Re}}^{0.54}$$

For calculating the average heat transfer from a sphere to fluids of Prandtl number in the range 2-380, the following expression is proposed:

$$N_{\mathrm{Nu}} \cdot N_{\mathrm{Pr}}^{-0.5}(\mu_w/\mu)^{0.25} = 2.7 + 0.12 N_{\mathrm{Re}}^{0.66}$$

This holds for Reynolds numbers in the range 1-300,000. The authors recommend that in the regions where natural convection effects are important (low Reynolds numbers and high Grashof numbers), these should be calculated from a natural convection correlation such as that given by MacAdams

$$hd/2k_f = 0.55(\triangle t d^3/8)^{\frac{1}{4}}(\rho^2 g\beta c/\mu k)_f^{\frac{1}{4}}$$

This is valid for the region $10^3 < (g\beta d^3\rho^2 c\triangle t/8\mu k)_f < 10^9$ or from the convection correlations given above. If the greater of the two numbers calculated in this manner is used, this will be within 20 per cent of observed values.

Turbulence-promoting Devices

The effectiveness of devices which increase turbulent forced-convection heat transfer at wetted surfaces was considered in a paper delivered by G. A. KEMENY and J. A. CYPHERS (60-HT-15). They investigated heat transfer and pressure drop for water in turbulent flow in an annular space between concentric tubes.

Surface spoilers, as these devices are termed, can be either of the integral or attached type or they may be of the protrusion or depression type. In the past most data have been obtained from protrusion spoilers consisting of helical springs, inserted to fit tightly into tubes. Other spoilers have consisted of separate rings which have been inserted into tubes or formed by stretching wires adjacent to a flat channel surface. The investigations of these configurations showed that the highest heat-transfer coefficients and friction factors are obtained when the spoiler protrusion pitch-to-height ratio approaches the value of 10. At ratios near 1 or 2 there is very little increase in heat transfer.

One of the disadvantages of attached spoilers is that they mask a portion of the surface available for heat transfer, so that the heat must be transferred first from surface to spoiler and then from spoiler to fluid.

KEMENY and CYPHERS show that this resistance can be significant with some devices when the Reynolds numbers are high. Of the spoilers investigated by them, that consisting of a semi-circular groove gave results sufficiently favourable as to warrant further investigation. An advantage is that depression spoilers of this kind can be expected to be cheap and less subject to deterioration through erosion than protrusion spoilers.

The table below gives details of the spoiler arrangements used.

TABLE I—Spoiler Configurations Tested

Spoiler height (average) in.	*Pitch to height ratio (nominal)*	*Explanatory remarks*
0		Smooth tube
0.0046	10	Spoilers integrally machined into tube surface
0.0049	20	Ditto, but with a 0.005-in. groove accidentally machined between 0.005-in. spoilers
0.0053	10	Ten-mill diameter wire wound into five-mill deep groove
0.0052 (depth)	10	Five-mill deep groove without wire

The following empirical expression was obtained for the ratio of friction factor (with spoilers extending over the entire wetted perimeter) and the friction factor for the smooth tube.

$$\frac{f_N}{f_B} = \mathrm{Re}^{0.3}\left(\frac{H}{D_e}\right)\left[7.50 - 2.63\left(\ln\frac{10H}{P}\right)^{8/5}\right]$$

If the spoiler friction factor alone is desired, then by substituting the Blasius equation for the smooth tube friction factor in this equation gives

$$f_N = \mathrm{Re}^{0.05}\left(\frac{H}{D_e}\right)\left[0.593 - 0.208\left(\ln\frac{10H}{P}\right)^{8/5}\right]$$

These equations apply to spoilers of semi-circular shape with P/H ratio line between 2 and 20. For all cases, if a P/H ratio of 10 is used the first equation reduces to:

$$\frac{f_N}{f_B} = 7.50\,\frac{H}{D_e}\,\mathrm{Re}^{0.3}$$

Symbols Used

c = specific heat, Btu/(lb$_m$)(°F);
d = sphere diameter, ft;
D = pipe diameter, ft;
g_c = proportionality factor, 32.2 (ft) (lb$_m$)/(lb$_f$)(sec^2);
h = average heat-transfer coefficient, Btu/(hr)(sq ft)(°F);
k = thermal conductivity, Btu/(hr) (ft)(°F);
N_{Gr} = Grashof number, $g\beta d^3\rho^2(\triangle t)/8\mu^2$;
N_{Nu} = Nusselt number, hd/k;
N_{Pr} = Prandtl number, $c\mu/k$;
N_{Re} = Reynolds number, $V_m\rho d/\mu$;
$\triangle t$ = average temperature difference between sphere surface and bulk fluid, °F;
β = volume coefficient of expansion for water, 1/°F;
μ = viscosity, lb$_m$/(ft)(sec).

Subscripts

f = average film condition;
ρ = density, lb$_m$/(cu ft).

Symbols Used

D_e = equivalent diameter of test configuration, 0.01571 ft;
f_B = friction factor determined from the Blasius law;
f_N = friction factor determined from equation (14), which is an empiric reduction of Nunner's data;
G = mass flow rate (lb/hr-ft²) = 4.080×10^5 times flow rate in gpm for tested configuration;
h = heat-transfer coefficient, Btu/hr-ft²-°F;
H = height of surface spoiler;
P = spoiler pitch, distance between adjacent spoilers.

In the case of heat transfer, the authors compared Nusselt numbers obtained experimentally for six spoiler configurations and from a smooth tube used by NUNNER, with Nusselt numbers calculated from Nunner's operating conditions using the Martinelli equation for fully developed turbulent flow.

The agreement is excellent and is was therefore suggested that the Martinelli equation may be used to estimate Nusselt numbers in tubular arrangements employing annular gap spoilers. It is shown that for all but the highest Reynolds numbers, e.g., 80,000 and greater, the Martinelli equation can be used for calculating the Nusselt number from the spoiler design configuration.

Heat Transfer in Annuli

Two papers by ROTEM and SHAI (60-HT-20, 60-HT-21) were devoted to heat transfer to water in internally heated annuli under stationary and pulsating flow. The work on stationary flow was undertaken as a preliminary to the investigation of pulsating flow and was motivated by the need for correlation in a field where no single agreed equation could be applied *a priori*.

The test data obtained by these authors were checked against a number of equations such as those of MONRAD, PELTON, DAVIES, WIEGAND and others; of existing equations, that of WIEGAND was found to be the best.

$$j_f = 0.023 \left(\frac{D_2}{D_1}\right) 0.45 \left(\frac{D_h G}{\mu}\right)_f^{-0.20} \quad \ldots.(1)$$

the maximum deviation for the local heat transfer coefficient being 9.9 per cent. A correction factor given by $1 + \frac{C}{L/D_h}$ was used.

The best correlation obtained by the authors is

$$j_f = 0.0182\ \mathrm{Re}^{-0.142} \quad \ldots.(2)$$

The greatest deviation from results calculated by this equation is 6.1 per cent for one single point; the remaining points were within 3.09 per cent of this correlation.

In the second paper the authors reviewed earlier attempts to investigate the effects of vibrations and pulsations upon heat transfer. They investigated the effects of vibrations of 1-2.9 cycles/sec with amplitude ratios up to 1.21. The scatter of the data obtained proved to be no more than that obtained for non-pulsating flow and it was therefore concluded that neither frequency nor pulsation ratio affected heat transfer in the series of tests undertaken. The range of Reynolds numbers were, however, narrow, i.e., 3×10^4 to 6.5×10^4. A small reduction in heat transfer rate was expected (see Fig. 5) which is based on a simple theoretical analysis presented by the authors.

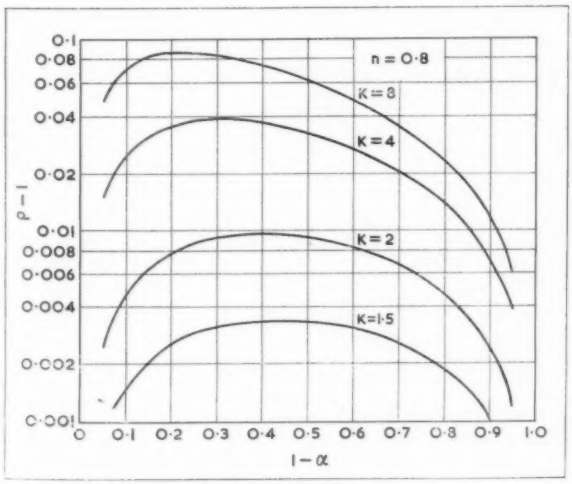

Fig. 4. The influence of low frequency pulsations. (α = duration of valve opening; ρ = ratio of Nu for pulsations to Nu for steady flow; K = ratio of maximum to minimum bulk velocity.)

Symbols Used

C = constant;
D_1 = inner (core) diameter;
D_2 = outer (envelope) diameter;
D_h = hydraulic diameter for both heat and momentum transfer = $D_2 - D_1$;
G = mass velocity per unit cross-section;
h = heat-transfer coefficient;
j = St × $\mathrm{Pr}^{2/3}$;
k = thermal conductivity;
L = length of duct from inlet;
n = exponent of Reynolds number;
Nu = Nusselt number = $h D_h/k$;
Pr = Prandtl number = $\mu c_p/k$;
Re = Reynolds number = $G D_h/\mu$;
St = Stanton number = Nu/Re Pr.

Subscripts

f = film.

Analysis, Results and Interpretation for Radiation Between Some Simply Arranged Grey Surfaces

The aspect of radiation heat transfer dealt with by SPARROW, USISKIND and HUBBARD (60-HT-9) was that of heat transfer in the space between two black concentric spherical surfaces in the presence of a participating gas in which an internal generation of heat occurs. In approaching the major problem of determining the temperature distribution throughout the gas, and the heat transfer to the bounding surfaces, they assume that the spherical surfaces are black and the gas grey, this latter assumption, as the authors recognise, being a deviation from the behaviour of real gases. However, the use of real gas properties results in complications in the mathematical treatment of the subject.

By applying the principle of conservation of energy, they obtain an integral equation for which solutions are given for a number of geometrical and radiation conditions.

The role of absorption coefficient on the gas emissive power is discussed at some length; thus for any fixed geometry of the surfaces the variation in emissive power throughout the gas is greater as the absorption coefficient increases, and the level of the gas emissive power (i.e., gas temperature level) increases with decrease in absorption coefficient. The latter result shows that if it is desired to maintain a low gas temperature, then a gas with a high absorption coefficient should be used. Another important factor is the length of path over which the radiation must travel before reaching the walls, since it affects the emissive power in two ways. As the spacing between concentric spheres increases, the level of the emissive power increases and its distribution across the gap becomes increasingly non-uniform.

In the discussion on the total rates of heat transfer to both surfaces, in the course of which the method of calculating both these quantities is described, the authors show that heat transfer at the outer surface is always greater than that at the inner surface, as is the heat transfer per unit area also.

An approximate analysis is presented which yields an equation whereby the dimensionless emissive power (defined in the text) may be estimated. For the case of the hollow sphere, and enclosures of diameter ratios of 0.05, and for products of absorptivity and outer diameter ratios of 1 and 2, this is shown to give results which compare well with those calculated by a more rigorous method described earlier by the authors.

To be concluded in Part III, which will follow in a future issue.

66.023

DEVELOPMENTS IN THE BULK SUPPLY OF CHEMICAL REAGENTS

The supply of a number of chemicals available in bulk was the field of a recent discussion event.* The chemicals considered in four of the papers were hydrogen, stabilised liquid sulphur trioxide, phthalic anhydride, hydrogen peroxide, while a further paper dealt with the transport of solids

The Bulk Supply of Hydrogen

DR. G. J. LEWIS read the first paper on "The Bulk Supply of Hydrogen". The cost of compressed hydrogen to the consumer is largely determined by the means of delivery which have to be adopted, namely, heavy steel cylinders. When large quantities of hydrogen are required, consumers are forced to install their own means of production or site their works near a source of by-product hydrogen. In 1955 new regulations encouraged an economic study of the delivery of hydrogen and, as a result, 3000 psig was the selected pressure for hydrogen in cylinders 2 ft in diameter and 20 ft long. Articulated vehicles 35 ft long, 8 ft overall width and maximum all-up weight of 24 tons were permitted; the design of transport vehicle is subject to approval by the Home Office. The cylinders were mounted in cradles bolted rigidly to the trailer chassis holding the three lower cylinders of a pyramid of six, and the assembly is held together by straps. The pressure and temperature of the gas in the cylinder are recorded after filling and after discharging and the quantity of hydrogen delivered is charged to the customer. The delivery service operates continuously to customers within an economic distance of the producer. The cost depends on distance, demand, the customer's storage facilities and the period of contract. In the U.S.A. the Linde Co. has conveyed purified liquid hydrogen for space vehicle rockets.

Bulk Handling of Stabilised Liquid Sulphur Trioxide

This paper was presented by Messrs. B. O. DAVIS, B.Sc., and A. T. ROYLE, B.Sc. Liquid gamma sulphur trioxide (SO_3) freezes at 16.8°C, boils at 44.8°C and readily polymerises to the beta form (M. Pt. 32.5°C), then to the alpha form (M. Pt. 62.3°C, variable to 91°C). The polymerisation is inhibited by the addition of about 0.1 per cent non-volatile boron compounds which restrict it to the relatively innocuous beta form; although this form, on long standing, may sink to the bottom of a storage vessel, no trouble has so far arisen where the outlet is at the bottom, because the contents are mixed by the addition of each new load of SO_3. The polymers melt to produce the gamma form and, if this is done in a closed vessel, the pressure will rise considerably. The tendency to polymerise is catalysed by traces of moisture such as are present in the atmosphere. Therefore, stabilised liquid SO_3 must be kept dry and out of contact with the atmosphere. Exposure to the atmosphere gives corrosive, white fumes. SO_3 must be kept at about 30°C to prevent it freezing in pipes and storage tanks. Venting, a necessity on storage tanks and filling units, must be through a scrubber over which 95-98 per cent sulphuric acid is circulated. Pipelines must be traced or jacketed by warm water. Vent lines are steam traced to prevent condensation of SO_3 vapours. Mild steel is used for most equipment for dry SO_3; valves and pumps are made of a stainless steel. Glands sealing against liquids are to be avoided wherever possible, and PTFE rings make the most suitable joints. All pipes should be self-draining back to the storage tank if possible, otherwise a drain-off valve should be placed at the lowest point; it is desirable to remove the last traces of SO_3 with a current of dry air. Flexible pipes made of Fluon are now available for use in loading tankers.

The six-ton road tanker is constructed of mild steel and is heavily lagged. The connections are grouped together in the dome; they are a combined filling and discharging point, connections for a vent line, a pressure-relief valve, a level indicator and a thermometer. During transportation warm air is fed into the dome to prevent solidification of SO_3 in the connections. Fitters who connect and disconnect the tanker to the customer's storage vessel wear complete suits of protective clothing. As an accident may cause dense fumes, adequate walk-ways complete with hand-rails are provided on the tanker. All valves and lines must be clean and dry before the tanker is loaded. When loading is complete, all flexible lines are drained, uncoupled, and blanked off to prevent fuming; they are washed and dried for re-use. The loading valves on the tanker are closed and sealed with blank flanges; the load is discharged from the tanker by compressed air. Asphalt loaded with inert filler is satisfactory for floors exposed to SO_3.

A Simple Installation for Handling Molten Phthalic Anhydride

The next paper, "A Simple Installation for Handling Molten Phthalic Anhydride", was read by DR. B. SHAW.

Phthalic anhydride is manufactured as a liquid (M. Pt. 131°C), and so handling it as the liquid instead of as solid flake eliminates the flaking operation, in addition to being safer and reducing handling costs.

A simple installation was described for storing molten phthalic anhydride and feeding it to a reactor making

* Developments in the Bulk Supply of Chemical Reagents: organised by the North-west Branch of the Institution of Chemical Engineers, Manchester, November 22, 1960.

Fig. 1. A vehicle for the transport of hydrogen gas. The six cylinders are each 2 ft in diameter, 20 ft in length, and the internal pressure is 3000 psig.

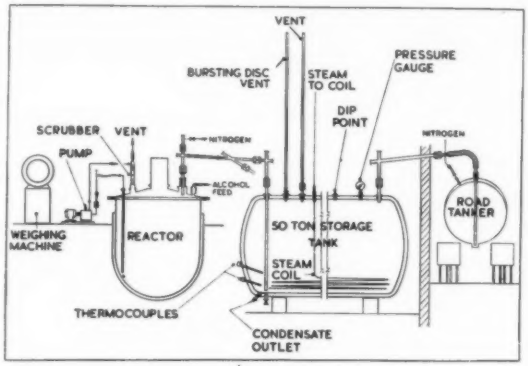

Fig. 2. An installation for unloading phthalic anhydride from road tankers.

Fig. 3. For road transport of solids. The container of this articulated vehicle has a capacity of 1000 ft³; it is designed for the air-assisted gravity discharge of a material with an angle of repose of 60°. The sloping base, fitted with a porous false bottom, causes the contents to flow to a central outlet.

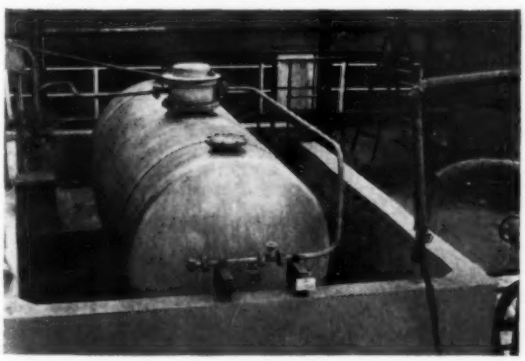

Fig. 4. A typical bulk storage installation for concentrated hydrogen peroxide. To the right is a LaBour self-priming pump constructed of 99.5 per cent Al. The bund allows spillage to be diluted with water.

phthalic esters. To prevent discoloration, stainless steel is used for storage tanks and transfer lines and the storage temperature is limited to 140-145°C. The liquid has a low viscosity, and a charge of 6000 lb is transferred through 50 ft of 2-in. line in approximately 20 minutes. For simplicity, transfer is by nitrogen blowing rather than pumping.

With efficient steam jacketing of all lines, valves and tank connections, and careful draining of lines after each transfer operation, blockages are prevented and operation of the installation is trouble free.

The Handling of Solids

This paper was given by MR. R. LEE, who described containers that transport solids in quantities larger than are contained in bags. Large tonnages of coal, iron ore, lime and sand are usually discharged from a railway wagon by a tippler, pneumatic suction or by a hydraulic slurrying system. The bulk handling of cement initiated developments in the design of pressure containers for use on road, rail and sea to handle materials other than cement. Individual companies designed equipment to carry their own specific materials according to their bulk densities and to their characteristics of flow down a slope. The design and the site of the receiving equipment decides the type of vehicle to be used on any handling system.

Many slides were shown and were grouped under transportable containers; road, rail and sea transport. Many road vehicles fluidised the powders with air supplied by the vehicle; others are air-assisted gravity discharged.

Bulk Handling and Storage of Hydrogen Peroxide

Messrs. K. H. RAWSTHORNE and J. A. WILLIAMS presented this last paper. The strengths of hydrogen peroxide as delivered are 35, 50, 70 and 85-90 per cent, weight/weight. Hydrogen peroxide decomposes exothermally into water and oxygen under certain conditions; at concentrations over 65 per cent by weight the heat released is sufficient to vaporise all the water present. Storage tanks are constructed of 99.5 per cent aluminium. A typical storage tank for 35 per cent grade holds 1250 gallons; it takes delivery from a 1000-gallon road tanker that carries its own pump to deliver to a height of 30 ft above the road surface. This horizontal tank is mounted on steel cradles or concrete piers insulated by strips of PVC to prevent corrosion. It has a bottom outlet with plugstick valve operated by a lever at the top of the tank. The filling pipe is connected to the centre man-hole cover provided with a vent which cannot seal, yet allows no airborne contamination to enter. If the concentration is greater than 35 per cent the storage tank is located away from organic solvents; no protection against frost is necessary, as the freezing point is lower than our extreme winter temperatures. The storage tank for concentrated hydrogen peroxide is emptied by a self-priming pump. The suction pipe enters the turret mounted on the centre man-hole of the tank which also carries the filling line. The top cover which carries a breather is secured to the turret by aluminium shear wires—this acts as a "blow-off" top if pressure builds up in the tank. The tank is surrounded by a wall or bund; water should be available to dilute any accidental spillage before running to waste. Storage tanks should be horizontal cylinders, with dished ends, of rolled sheet and welded by an inert gas electric arc process. The tanks are cleaned and passivated by spraying with dilute caustic soda, then dilute nitric acid and finally with dilute hydrogen peroxide, washing out between each operation. The delivery tankers are 1000 or 2000 gallons capacity for 35 and 50 per cent grades. The 85-90 per cent grade is distributed in 600-gallon tankers that carry a pump and an additional tank filled with water for dealing with accidental spillage. For shipping purposes a 500-gallon demountable tank with a "blow-off" top turret is fitted with specially strengthened cradles.

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THE GRAPHICAL CALCULATION OF CARBON AND LOW ALLOY STEEL FUSION-WELDED PRESSURE VESSEL SCANTLINGS

by J. L. RYDER

Section I—Shells

THIS is the first of a series of four graphs for estimating pressure vessel scantlings to B.S. 1500:58. The next three graphs will deal with dished and flanged end pressings and will appear in subsequent issues of *British Chemical Engineering*.

This graph enables the thickness (max. 1½ in.) of shells of vessels up to 120 in. diameter and 500 psi design pressure to be obtained easily. Conversely, it will show the permissible design pressure of an existing vessel shell providing diameter, thickness and joint efficiency are known.

The curves are drawn to the equation,

$$t = \frac{p\ D_i}{2f\ J - p}$$

taken from B.S. 1500:58, Section Three E, Equation 3.

Three necessary conditions are imposed on the curves, and these are:

(1) No allowance is made for corrosion. In effect, this means that to whatever thickness is determined from the graph should be added an allowance equivalent to the corrosion expected during the life of the vessel.

(2) The material-design stress is 15,700 psi, i.e., the design metal temperature does not exceed 650°F for normal boiler-quality mild-steel plate.

(3) A joint efficiency of 0.7 has been presumed, as it is thought this is probably the most widely accepted joint factor used in industry. However, to allow for other joint efficiencies the table below gives approximate comparison factors for joint efficiencies of from 0.70 to 0.95 in two

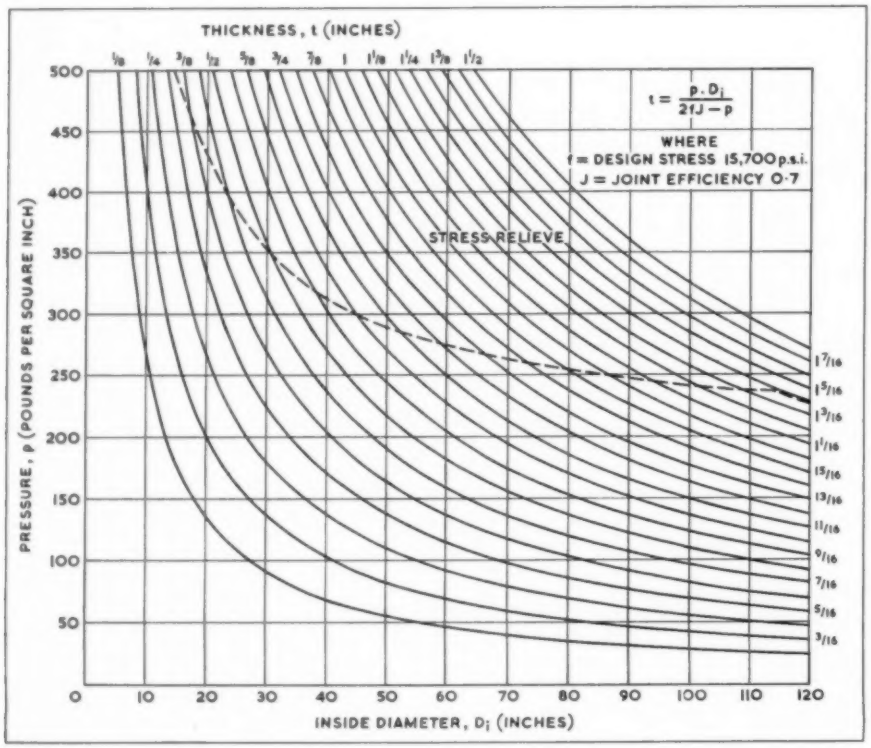


Chart for determining wall thickness of low alloy and carbon steel pressure vessels to B.S. 1500:1958.

stresses; namely 14,500 and 15,700 psi, corresponding to 26 tons/in.^{2} tensile and 28 tons/in.^{2} tensile material respectively.

Some British Standard materials classified under the 26 ton tensile range and used in the manufacture of pressure vessels are: B.S. 14; B.S. 1633, grade B; B.S. 1501—151, grade B; B.S. 1501—161, grade B.

Those in the 28 ton tensile range include: B.S. 14; B.S. 1633, grade C; B.S. 1501—151, grade C; B.S. 1501—161, grade C.

It will be appreciated that vessels whose plate thickness is $1\frac{1}{4}$ in. or greater, constructed in accordance with the code, should be stress relieved. This would indicate that a higher joint efficiency (0.80) may be used. The five curves representing $t = 1\frac{1}{4}$ in. to $1\frac{1}{2}$ in. inclusive are included therefore for guidance only when referring to a 0.7 joint efficiency. (See also B.S. 1500:58, Section Four D, Clause 2.)

Joint Conversion Factors (F)

Joint Efficiency (J)	0.70	0.75	0.80	0.85	0.90	0.95
Stress (f)	F					
15,700	1.00	0.934	0.875	0.824	0.779	0.737
14,500	1.082	1.012	0.948	0.893	0.843	0.798

Example

Determine the thickness of a shell, the design pressure of which is 225 psig, the diameter new and uncorroded is 5 ft and the corrosion allowance $\frac{1}{16}$ in.

The material of construction is B.S. 1501—151, grade B, and the vessel is fabricated to Class I standards, i.e., includes stress relief, radiography and full mechanical tests. The joint efficiency, therefore, would be 0.95.

From the graph:

When $p = 225$ and $D_i = 60.125$,

$t = \frac{5}{8}$ in.

From the table:

When $f = 14{,}500$ and $J = 0.95$,

$F = 0.798$.

The design thickness, therefore, is:

$$t = (0.625 \times 0.798) + 0.0625$$
$$= 0.498 + 0.0625$$
$$= 0.5605.$$

The nearest commercial thickness of plate obtainable greater than 0.5605 is $\frac{9}{16}$ in., which would be used in this instance.

The above information extracted from B.S. 1500:1958, *Fusion Welded Pressure Vessels for use in the Chemical, Petroleum and Allied Industries*, is reproduced by permission of the British Standards Institution, 2 Park Street, London, W.1, from whom official copies of the complete standard may be obtained—price 40 shillings.

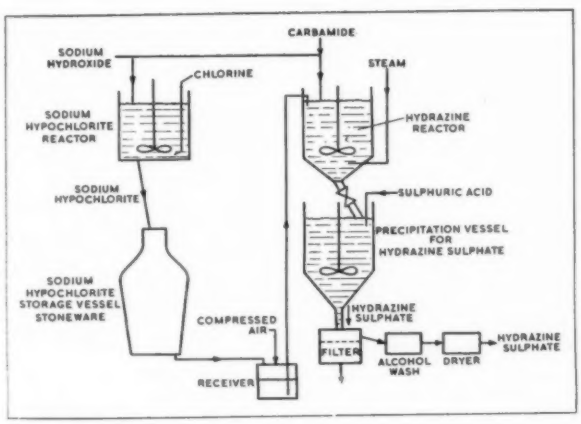
Hydrazine Manufacture at Hungarian Power Plant

IN order to provide a plentiful supply of hydrazine for treating boiler feed water, a plant for this chemical has been constructed on the site of Hungary's largest thermal power station, the Inota power plant; its capacity is sufficient to provide the hydrazine required by other Hungarian power plants.

At the Inota plant, hydrazine is produced according to the following reaction

$$NH_2CONH_2 + NaOCl + 2NaOH \rightarrow N_2H_4.H_2O + NaCl + Na_2CO_3$$

The sodium hypochlorite required for this reaction is produced by bubbling chlorine through sodium hydroxide in a cooled tank fitted with an agitator. The sodium hypochlorite is then brought into contact with an alkaline urea solution in a similar agitated system, and the reactants heated to 90°C; the reaction takes place with vigorous foaming. The sodium hypochlorite solution is fed to a stoneware receiver and from there to a pulse column and is finally forced by compressed air to the hydrazine reactor. The reaction mixture must be instantly cooled to prevent the occurrence of detrimental reactions.



The next step is the separation of hydrazine from the solution which is accomplished quite simply by adding sulphuric acid to precipitate hydrazine sulphate, in a tank of conical bottom fitted with a mechanical agitator. The product is then filtered, a fraction of the water being eliminated by alcoholic washing, a feature of the stage of the process which shortens the drying time considerably. However, despite the improvement the time required for drying in the tray drier is still rather long, amounting to 8-12 hr at a drier temperature of 60-75°C.

For process efficiency, care should be taken to prevent heavy metal salts from entering the system or else a rapid decomposition will occur reducing the hydrazine yield to as little as 25-30 per cent. The equipment for the early stages is therefore made with PVC linings and the pipelines are also made of PVC. The result is the production of hydrazine purity 96-97 per cent.

The next step is to obtain hydrazine hydrate from hydrazine sulphate. For this purpose the hydrazine sulphate is fed to a vessel containing a suspension of sodium hydroxide in methanol, the requisite mixing action for suspension and reaction being provided by the agitating system with which the vessel is equipped. The reaction yields hydrazine hydrate and sodium sulphate; since the sodium sulphate is insoluble in methanol, it is readily separated by filtering. The methanol solution thus obtained contains 10 per cent hydrazine hydrate and it is subsequently concentrated to 30 per cent in an aluminium apparatus, a form in which it is readily marketable.

The plant is compact, and has a high degree of automatic control. The control panel is of the graphic type.

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BCE 9239 for further information

CHEMICO BUILDS NITRIC ACID PLANT IN SIX MONTHS

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NOMOGRAM FOR HEAT TRANSFER COEFFICIENT IN AGITATED KETTLES

by L. K. DORAISWAMY
National Chemical Laboratory, Poona, India

CHILTON, DREW and JEBENS[1] proposed the following two equations for evaluating kettle-side heat-transfer coefficients in agitated kettles:

(1) for jacketed kettles:

$$\left(\frac{h \cdot d}{k}\right)\left(\frac{\mu_s}{\mu}\right)^{0.14} = 0.36\left(\frac{P^2 \cdot N \cdot \rho}{\mu}\right)^{\frac{2}{3}}\left(\frac{C_p\,\mu}{k}\right)^{\frac{1}{3}}$$

(2) for kettles with coil (the index 0.62 in the original equation has been replaced by 2/3 by SMITH[2]):

$$\left(\frac{h \cdot d}{k}\right)\left(\frac{\mu_s}{\mu}\right)^{0.14} = 0.87\left(\frac{P^2 \cdot N \cdot \rho}{\mu}\right)^{\frac{2}{3}}\left(\frac{C_p \cdot \mu}{k}\right)^{\frac{1}{3}}$$

In order to present a nomographic solution to these equations, which are of considerable use in the design of reaction kettles and heat-exchange vessels, the following rearranged expression is employed:

$$h = K\,\frac{P^{\frac{2}{3}} \cdot N^{\frac{2}{3}} \cdot \rho^{\frac{2}{3}} \cdot k^{\frac{2}{3}} \cdot C_p^{\frac{1}{3}}}{\mu^{\frac{1}{3}} \cdot d \cdot \left(\frac{\mu_s}{\mu}\right)^{0.14}}$$

where $K = 0.87$ or 0.36.

A nomograph based on this expression has the advantage that the value of h can be determined directly from the variables without first evaluating any dimensionless group. The majority of heat-transfer nomographs require separate evaluation of the constituent dimensionless groups.

The use of the nomograph presented is illustrated by the following example:

Nitrobenzene is to be heated to 100°C in a 5-ft-diameter vessel provided with a 4-ft-high paddle stirrer having an rpm of 200. For nitrobenzene at 100°C, $\mu = 0.6$ c.p., $k = 0.095$ Btu/ft °F hr and $C_p = 0.41$ Btu lb °F. Assuming $\left(\frac{\mu_s}{\mu}\right) = 0.5$, determine h.

(1) Locate $\left(\frac{\mu_s}{\mu}\right) = 0.5$, connect it with $d = 5$ and extend the line to point a; (2) join this point to $\rho = 73.5$, locating point b on the diagonal; (3) connect $N = 200$ with b and mark point c; (4) join $\mu = 0.6$ to $k = 0.095$, locating point d on the diagonal; (5) join points c and d, extend to e and proceed along appropriate guide line to f; (6) join this point to $c_p = 0.41$ and locate point g on the reference line. Connect g with $P = 4$ and read the value of h as 45 (for jacket) and 100 (for coil).

Symbols Used

C_p = specific heat, Btu/lb °F;
d = inside diameter of vessel, ft;
h = film coefficient of heat transfer for jacket or coil, Btu/hr ft² °F;
k = thermal conductivity, Btu/ft °F hr;
N = agitator speed, rpm;
P = height of paddle, ft;
ρ = density, lb/ft³;
μ = viscosity, c.p.;
μ_s = viscosity at surface temperature of jacket or coil, c.p.

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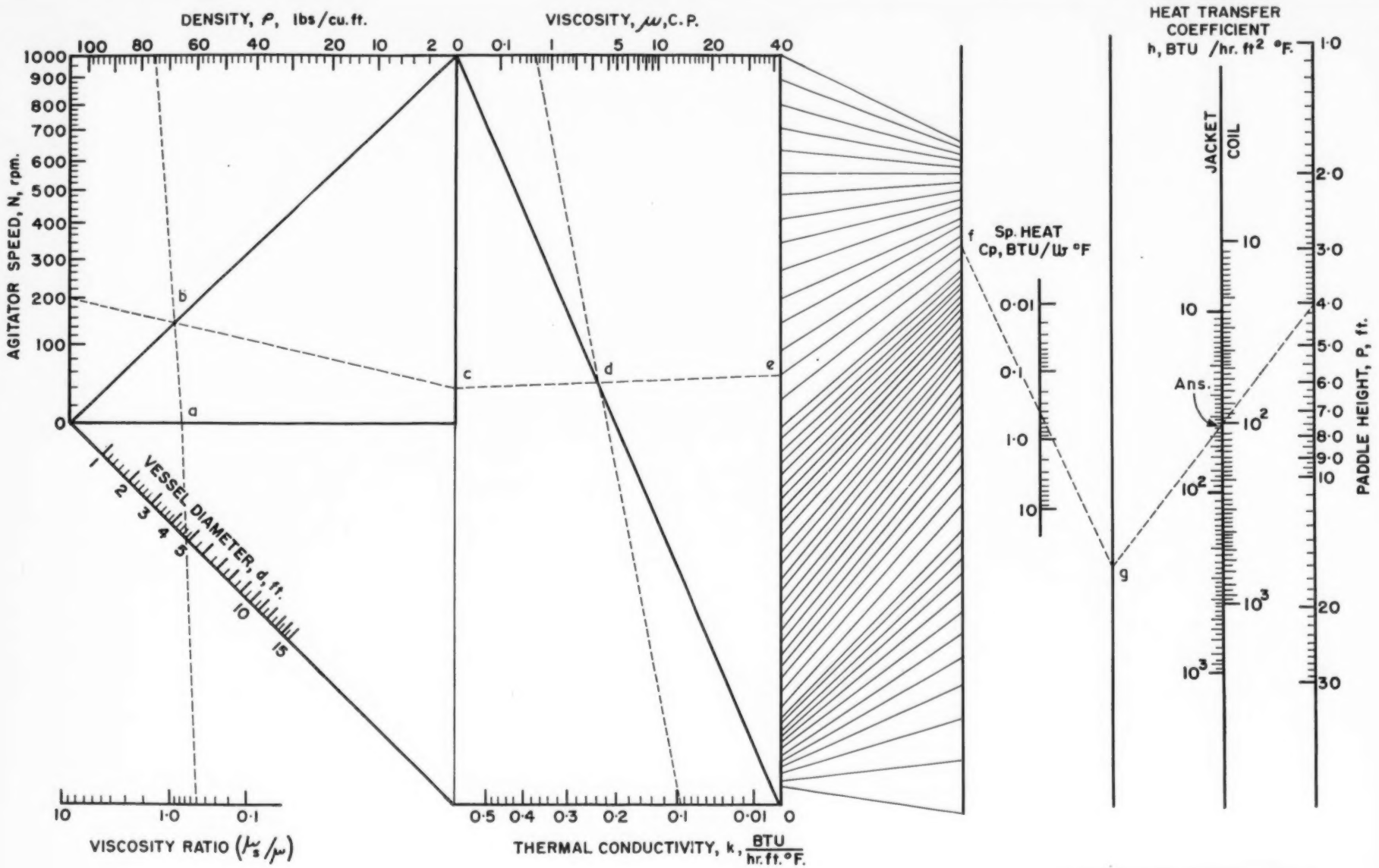
DENSITY, ρ, lbs/cu.ft.
100 80 60 40 20 10 2 0
VISCOSITY, μ, C.P.
0·1 1 5 10 20 40
AGITATOR SPEED, N, rpm.
1000 900 800 700 600 500 400 300 200 100 0
a
b
c
d
e
f
g
VESSEL DIAMETER, d, ft.
1 2 3 4 5 10 15
VISCOSITY RATIO (μs/μ)
10 1·0 0·1
THERMAL CONDUCTIVITY, k, BTU/hr.ft.°F.
0·5 0·4 0·3 0·2 0·1 0·01 0
Sp. HEAT Cp, BTU/lb °F
0·01 0·1 1·0 10
HEAT TRANSFER COEFFICIENT h, BTU /hr. ft² °F.
JACKET
COIL
10 10 10² 10² 10³ 10³
Ans.
PADDLE HEIGHT, P, ft.
1·0 2·0 3·0 4·0 5·0 6·0 7·0 8·0 9·0 10 20 30

British Chemical Engineering
NOMOGRAM NO. 57

RECENT CHEMICAL ENGINEERING THESES FOR HIGHER DEGREES

Corrosion of Iron and Copper Pipes by Oxygenated Moving Waters

by B. P. Hitchen (Ph.D., Manchester University)

The corrosion of iron and copper pipes by oxygenated moving waters is described, particular attention being given to the effects of flow velocity and dissolved oxygen concentration.

An electrochemical flow cell has been developed which facilitates the study of velocity effects without the added complication of scale formation; at the same time the cell can be adapted to investigate the effects of scale growth.

The corrosion of iron is shown to be under cathodic control, and that of copper under mixed control; the corrosion rate of both is shown to increase with flow rate.

The control exerted by boundary layer formation on the corrosion rates is illustrated and discussed. The cathodic reactions are shown to require a finite time to attain their equilibrium values.

The Effect of Surface Tension Changes on the Minimum Wetting Rate in a Wetted Rod Distillation Column.

by D. T. Binns (Ph.D., Manchester University)

Minimum wetting rates (M.W.R.) were measured for the systems methanol-water and n-propanol-water under distillation mass transfer conditions. Concentrations of the phases were arranged so that the alcohol was preferentially transferred into the liquid from the vapour or into the vapour from the liquid, thus reducing or increasing the surface tension of the liquid film according to whichever way the mass transfer took place.

Results showed that the M.W.R. was much higher when the surface tension was reduced than when it was increased, even though the liquids had the same bulk properties in each case.

The effect of surface tension differences in the film causing film breakdown was investigated and discussed in terms of GREENBERG's[1] theory. Quantitative results were obtained relating the difference in surface tension at the point of film breakdown to the M.W.R.

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[1] GREENBERG, A. B., *Ph.D. Thesis*. Purdue, 1956.

The Oxidation of Transformer Oils

by R. T. T. Bell (Ph.D., Manchester University)

It has been demonstrated that both oxidation inhibitors and promoters are naturally present in distillate oils. Inhibitors have been known to play a large part in determining the oxidation resistance of oils, but the presence of natural oxidation promoters has not previously been established. These promoters have been extracted by dilute sulphuric acid and have also been shown to be strongly adsorbed by silica gel. They were therefore concluded to be basic in nature, possibly heterocyclic nitrogen compounds.

Oils were separated into predominantly saturate and predominantly aromatic fractions by both silica gel and alumina absorption chromatography. Iso-octane, benzene and methanol were used as eluents in that order. The oxygen absorption characteristics of these fractions and the mixtures of these fractions have shown that the stability of an oil to oxidation is determined to a large part by interaction between these natural inhibitors and promoters and the saturate components of the oil. There was also evidence that the natural inhibitors acted synergistically with the more highly condensed aromatic compounds present in the methanol eluated fraction of the oil in inhibiting the oxidation of the saturate components. Abnormally high stabilities of oils recombined from the chromatographically separated fractions have been reported by several authors. This anomaly has been demonstrated to be due to the incomplete elution of oxidation promoters from the silica gel packing in the chromatography column.

Acid washing of transformer oil distillates removes or destroys most of the oxidation promoters.

A Study of the Steam Distillation of the Aniline-Water System

by J. T. Chiam (M.Sc., Manchester University)

This investigation was carried out to ascertain the factors which were likely to cause deterioration in the performance of an industrial random-packed column in aniline stripping.

Investigations made on the operation of a 3-in.-diameter column with three perforated plates over the liquid rates of 300-1080 lb/ft² hr with a constant steam rate of 210 lb/ft² hr indicated that the Murphree plate efficiency was in the range 60-80 per cent. The variation of the gas and liquid ratio over a wide range of liquid rates was found to have no significant effect on the plate performance. The experimental data pointed to the fact that the stripping of aniline in a perforated plate column is essentially governed by the normal gas-film resistance controlling process.

Quantitative data were obtained for a wide range of liquid and gas flow rates and indicated that the major single factor which could account for the deterioration of column performance was the maldistribution of the liquid.

The results indicated that the performance of the column was seriously affected by maldistribution as the dimensionless absorption factor mG_m/L_m was increased beyond unity.

An industrial column reported to be operating inefficiently was investigated and found to be operating with an mG_m/L_m value of 2.0; it was suggested that this high operating factor was the reason for the abnormally high H.E.T.P. values obtained.

Natural Convection Mass Transfer in Solid-liquid and Liquid-liquid Systems

by N. J. M. Connolly (Ph.D., Manchester University)

Experimental data are presented for mass transfer by natural convection from vertical and horizontal surfaces in small cells using the systems benzoic acid-water, saliocyclic acid - water and succinic acid-water. The acids were used in the form of cast plates ranging in size from 1.5 by 1.25 cm to 6.0 by 5.0 cm in the case of horizontal plates, and in height from 1 to 2 in. in the case of vertical plates.

The work on vertical surfaces was done to confirm the results of WILKE, TOBIAS and MORRIS EISENBERG.[1] The data obtained by the author can be expressed by the equation:

$$Sh = 0.57\,(Sc.Gr)^{\frac{1}{4}} \quad \ldots . (1)$$

for $(Sc.Gr) = 7 \times 10^7$ to 8×10^8.

This result is in good agreement with the findings of the above authors and with corresponding heat transfer data.

The fact that natural convection transfer coefficients have in general been found to be proportional to the nth power of the driving force, where n may be $\frac{1}{4}$ or $\frac{1}{3}$ depending on the type of transfer involved, has been used to evaluate the correct mean concentration difference for mass transfer from horizontal surfaces by free convection. On this basis a general correlation has been produced for mass transfer under these conditions, which may be expressed by the equation:

$$Sh = 0.14\,(Sc.Gr)^{\frac{1}{3}} \quad \ldots . (2)$$

for $(Sc.Gr) = 5.0 \times 10^7$ to 4.0×10^{10}

This result again shows good agreement with the corresponding heat transfer relationships.

The effects of cell size and time on the mass transfer coefficients have been investigated, mainly in the case of horizontal surfaces. Results show that while cell depth has no definite effect, small transfer areas and short times give high transfer rates.

Sh = Sherwood Group for mass transfer.
Sc = Schmidt Group.
Gr = Grashof Group.
Nu = Nusselt Group which numerically = Sh.

REFERENCE

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Cast iron tube box: 7 ft. 10 ins × 4 ft. 11 ins × 8 ins deep; weight 32½ cwt.

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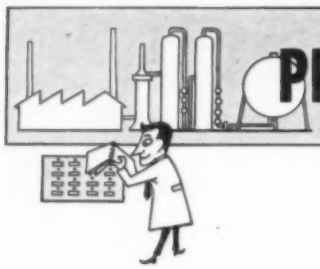


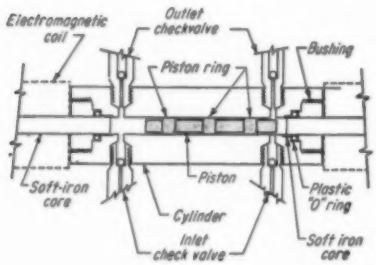
PROCESS ENGINEER'S NOTEBOOK

Electro-magnetic Circulator for Gases

A SIMPLE ELECTRO-MAGNETIC positive-displacement pump for circulating gases at low flow rates makes use of a piston consisting of a plastic-coated bar magnet of the type used in magnetic stirrers for its piston, with its other main components a pair of electro-magnets and a non-magnetic stainless-steel cylinder. Despite its simplicity (it has only three moving parts), it is able to give virtually a perfect positive-displacement characteristic and it has the additional virtue of preventing contamination.

By reversing the polarity of the electro-magnets the piston is readily made reversible; and by having inlet and outlet valves at either end of the piston a double-acting characteristic is obtained.

The soft iron cores at each of the pump ends are sealed against the cylinder by means of "O" rings and threaded stainless-steel bushes. The piston itself is covered with the same material, which not only gives a protective surface but also serves as a lubricant.

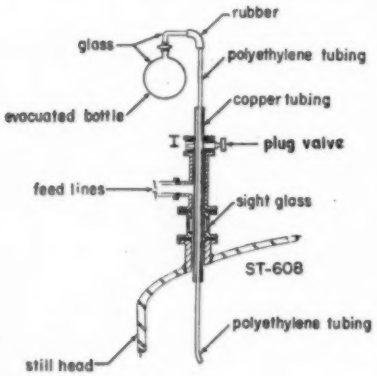


The electrical circuit has a motor-driven timer with two cams to give two pulses per second, each pulse lasting less than 0.2 sec. The direction of current flowing through the electro-magnetic coils is reversed at each pulse.

Product Engineering, 5, Jan. 2, 1961.

Sampling from Batch Reactor

IN THE PILOT-PLANT scale preparation of dimethylcadmium, which was required for coupling organic reactions, a method of sampling was required to determine when the dimethylcadmium reaction was complete.



The method of sampling evolved is shown in the accompanying sketch. The device consists of an evacuated flask attached to a length of polyethylene tubing. When it was desired to sample, this tubing was threaded through a length of copper tubing projecting into the vessel. The copper tubing was introduced shortly before sampling and was passed through the plug cock and sight glass into the still. The polyethylene tubing to which the sampling flask was attached was then threaded through the copper tube until its lower end reached the vessel contents.

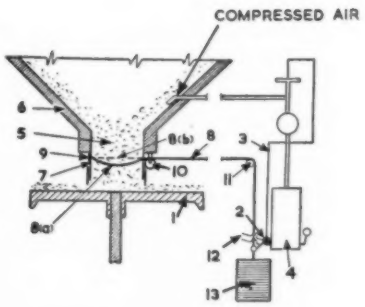
The sample was then readily withdrawn by opening the cock on the flask. This done, both polyethylene tube and copper tube were withdrawn, and the plug valve closed.

(Abstracted from "Organic Pilot Plant Operations", Colin and Gillin, *C.E.P.*, 56, 9, 1960.)

Uninterrupted Solids Transfer from Bunkers

THE FOLLOWING IS A description of a system for controlling automatically the operation of pneumatic looseners fitted near the base of a feed hopper. A 15 mm diameter steel cable (8 in the accompanying figure) passes through a stationary tube (7) fitted to the mouth (5) of the hopper (6). The cable is some 150 mm below the discharge of the bunker. At the far side of the stationary tube the cable is fixed at point 9. It passes over guide pulleys (10 and 11) and is connected securely at (12) to the valve (2) of airline (3). The latter connects with cylinder (4). A counter-weight (13) of some 15 kg is attached to the lower end of the cable. When the solids are discharging normally from the hopper their weight deflects cable (8) to the position 8a. This causes the counter-weight to rise, and through the connection to the valve (2) the compressed air supply is shut off from the pneumatic loosening system. If the solids jam, the flow from the mouth of the hopper and the pressure on the cable become zero. The counter-weight then drops, since the cable reverts to its original position (8b). As a result, valve (2) opens and allows compressed air to enter the hopper as soon as the solids build up to a position immediately above the cable.

This device ensures that there is a steady flow of material on to the table feeder (1). When the compressed air for loosening has dealt with the retarded flow of material, the movement of solids forces the cable downwards once more and the lifting of the counter-weight causes the compressed air supply to be interrupted.



This system, which is now established at a Russian chemical factory (The Rutchenkovo Coke & Chemical Works), has saved about 50,000 kWh and about £2000 per year.

(M. P. Zherdev, *Coke and Chemistry, U.S.S.R.*, 6, 12, 1960.)

Air-operated Mixer in Synthetic Phenol Dehydration

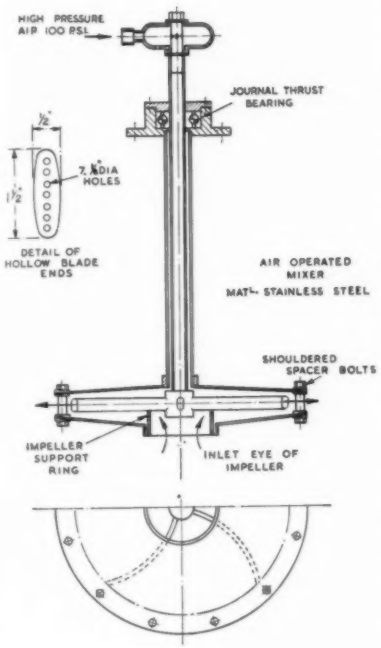
When crude phenol is sprung from sodium phenate it is separated from the aqueous layer in a decanter, but at this stage the phenol contains too much water for it to be economically separated in a distillation column and it is therefore dehydrated by washing with 96 per cent sulphuric acid.

This acid must be strong enough to remove the water, but not so strong as to cause charring and decomposition of the phenol.

Through the considerable difference in gravity between the two phases the mixing must be very vigorous, and although this can be performed for the acid washing of tar acids with a steam jet mixer, this is unsatisfactory for the higher-water-content synthetic crude phenol.

Compressed air can be used in place of the steam, but it has been found that the requirements when air is used alone are so great that this is uneconomical, mainly because the air jet has a low mixing efficiency.

A combination of air jet and mechanical mixer, as illustrated in the sketch, offered an economical solution, and a similar device has been reported in the literature for the bleaching and deodorising of palm oil.



The principle is that of Hero's wheel, since the change of momentum of the high-pressure air exhausting from the jets at the hollow blade tips drives the blades around at high speed in the manner of a centrifugal pump impeller. Fixed stainless-steel shrouds are provided, giving in the present case single entry to the impeller but in other cases double entry. The liquids are mixed between the shrouds by the blades, leaving finally at the periphery where further mixing is performed by the air leaving the jets at the blade tips.

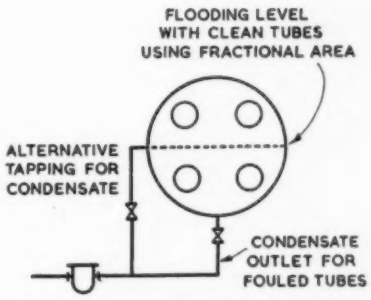
F. Molyneux

A Simple Method of Surface Variation in Reboilers

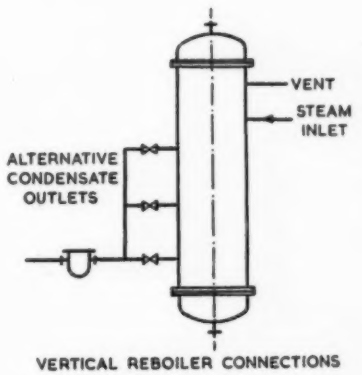
Since in practice reboilers usually operate with considerably fouled surfaces, the overall coefficients obtained on plant are usually rather low: e.g., 100-120 Btu/ft² hr °F.

With the present state of knowledge of heat transfer to boiling liquids, these values for overall coefficients must be used for design purposes, such as the estimation of the reboiler-heat-transfer surface required for a particular duty.

When first commissioned with clean surfaces, reboilers may operate with coefficients of the order of 500-550 Btu/ft² hr °F; but to maintain a constant liquor temperature is difficult, because the temperature of the condensing steam falls too low to maintain sufficient pressure head to clear the condensate from the reboiler. In these circumstances, alternate flooding and discharge of this condensate takes place, and, as a result, severe fluctuations in temperature occur.


FLOODING LEVEL WITH CLEAN TUBES USING FRACTIONAL AREA
ALTERNATIVE TAPPING FOR CONDENSATE
CONDENSATE OUTLET FOR FOULED TUBES

SECTION THROUGH HORIZONTAL REBOILER

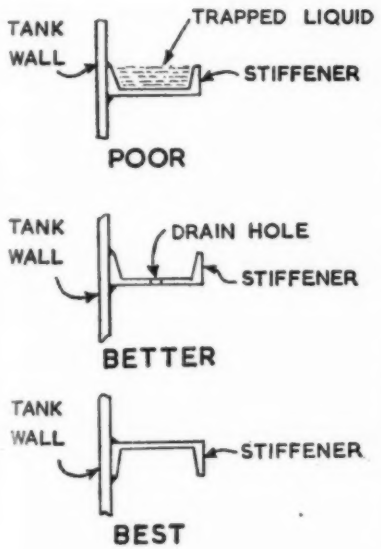


VERTICAL REBOILER CONNECTIONS

Constant conditions can be maintained, however, by fitting alternative condensate tappings on the reboiler shell so that only the requisite heat-transfer area is exposed to condensing steam, thus providing a steam temperature sufficiently high to maintain a pressure for condensate discharge.

F. Molyneux

Protecting Tank from Corrosion



An important consideration in designing vessels and tanks for corrosion resistance is to avoid moisture traps and pockets. This applies mainly to stiffeners of the channel type, which, if wrongly attached to the vessels, can form excellent pockets for retaining moisture and other foreign materials. Circumstances of this kind lead to concentration-cell corrosion.

The best manner of attaching channel-type stiffeners to vessels is to have their flat surfaces uppermost. If this cannot be done, or is overlooked in the first place, then the channels should be drilled to provide drainage for harmful liquids.

Another source of deterioration arises when a tank is mounted on a concrete pad and grouted in with an asphaltic compound. In time, through ambient temperature changes or operating temperature gradients, the grouting may crack and provide an excellent trap for moisture and corrosive substances. It is better to make the base in the first place with grooves placed at regular intervals for drainage. Or the tank may be mounted on legs.

Book Reviews

Polythene

Edited by A. Renfrew and P. Morgan
Iliffe & Sons Ltd., 1960, London 165/-.

THAT a work of this size and scope should merit a second edition within the space of three years is in itself evidence both of the success of the work and of substantial developments in the technology of polyethylene. The book as a whole merits the highest praise, for the editors have succeeded in obtaining from their contributors chapters of considerable specialist content, and in combining and arranging them as a coherent work.

The chapters are arranged in three parts, the first of which embraces methods of manufacture and polymer properties, the second dealing with processing techniques, whilst the third treats applications. The early chapters provide fascinating general reading on the history and development of polythene, and the authoritative discussion of modern manufacturing processes (ch. 2) illustrates very well the enormous post-war expansion of technology *and* production. Chs. 3, 4 and 5 provide theoretical discussion of the mechanism of ethylene polymerisation and the structure of the polymer, as well as a valuable source to the literature on this subject.

Among the chapters on manufacture and applications, some may prove of especial interest to the readers of this journal. Thus chs. 8 and 9 furnish an exhaustive treatment of the general mechanical properties and chemical resistance of polythene. Also of direct interest to the chemical engineer are those dealing with pipe (ch. 33) and chemical plant (ch. 34). Although the former is strictly applicable only to cold water service, there is much of general interest, especially on the subject of pressure drop, which is usually absent from chemical pipeline data. Ch. 34 describes the methods and techniques available for the construction of items of plant, and evaluates them one against the other. Also of interest are comparative cost figures, a welcome inclusion indeed.

On the whole, then, this book is strongly recommended, and contains items of special interest to chemical engineers.

T. K. Ross

Dechema Monographien

Vol. 37, Nr. 576-578
Verlag Chemie G.m.b.H., Weinheim, 1960, 277 pp.

THIS paper-back volume is devoted to the progress of distillation technique and it contains three interesting papers. The first, entitled "Properties of Two-phase Flow in Packed Columns", is written by Dr.-Ing. H. BRAUER. The author surveys the present knowledge on pressure drop correlations in packed columns and establishes a simple model of a packed column for a single-phase flow. This is used as a basis of two-phase flow considerations. The effect of liquid flow on pressure drop is introduced in the form of a parameter related to liquid hold-up. The theoretical considerations are supported by experimental results obtained on a 1½-in. column using various packings and flow conditions. The results are expressed in a dimensionless form which enables the calculation of pressure drop and liquid hold-up.

The third paper is on "Experimental and Theoretical Investigation of Fractionation in the Light of Similarity Theory". Experiments on a 6-in. column packed with Raschig rings have been carried out to investigate the effect of vapour and liquid flows on the fractionation efficiency. By introducing dimensionless constants, the results could be correlated by a single curve.

The second contribution, by Dr.-Ing. A. HUPE, is discussed last, as it deserves more space. It is a delightful paper entitled "Control of Continuous Distillation Columns" and is written by a mechanical engineer with special interest in instruments control. This paper should be of considerable interest to chemical and instrument engineers engaged on the design of control systems for continuous distillation columns. First, a summary is given with numerous references on the published work to date. Next, sets of general equations are derived for dynamic and static behaviour of a binary system undergoing rectification, as a function of feed, reflux and vapour flows and compositions. Some simplifying assumptions are introduced to make these equations more manageable. The equations are solved on a digital computer for various disturbances at a number of levels, viz., composition and flow rate of feed, boil-up rate and reflux, for both the dynamic and static conditions. The faint hope that some new and unexpected results are forthcoming is soon dispelled. The results fall into the category of "obvious" to engineers experienced with operation and control of distillation plants. Thus we find that the fastest response to change is at a point of maximum concentration gradient. This does not necessarily correspond to the optimum position of the detecting element. However, it is comforting to feel assured that the usual rules of thumb applied in the design of control systems have some theoretical justification. Methods are given for estimating and predicting the rate of changes in composition at the optimum points in the column and the corresponding time constants.

This stimulating paper contains some new ideas and is recommended to all interested in this subject. It is regrettable that this "Penguin" edition of "Dechema Monographien" is not more readily available.

T.A.K.

Technology of Non-Metallic Coating

by A. Ya Drinberg, E. S. Gurevich and A. V. Tikhomirov
Pergamon Press Ltd., 1960, 547 pp. 80/-.

THIS volume is a translation of a Russian text-book intended to support a course in non-metallic coatings, and thus probably has no equivalent in the British literature. It is in itself a very good example of the training given to some Russian technical graduates, for it is described as being suitable for chemical engineers specialising in surface coatings. Whilst the subject-matter is unfamiliar to us in this context therefore, it is none the less important.

The book commences with the simple physical and chemical principles of corrosion and corrosion prevention, and proceeds to an examination of the properties of solid surfaces and their interaction with coatings. The factors influencing the formation of coatings and their variety and properties are also reviewed. An excellent chapter on the ageing of coatings and the role of oxidative and thermal breakdown in the total process concludes what one may term the fundamental section of the book.

The remainder of the text falls into two parts, in the first of which the preparation of metal surfaces, the chief forms of coating, and the techniques of coating metal, wood, concrete and other surfaces are described. Finally, five chapters are devoted to the design and use of tools, equipment and plant necessary for the coating of machinery and components on the industrial scale.

Although none of the techniques or production methods will be found to be new, their description and collation within a single book is valuable. The references and bibliography are almost entirely of Russian origin, so that individual chapters are a useful source of the literature in each field. The publishers and translator are to be congratulated on the format and general style of the book, which is available within a reasonable time from the publication of the original.

T. K. Ross

Wärmeaustauscher

by Professor Dr.-Ing. Romano Gregorig
Verlag H. R. Sauerlander & Co., Aurau and Frankfurt/Main, 1959, 500 pp.

THIS is Volume IV of the series "Grundlagen der Chemische Technik" edited by Profs. MOHLER and FUCHS in Switzerland. This volume deals with heat exchangers in all aspects of design, construction, manufacture and operation, and in this respect it differs somewhat from the well-known text-books on heat transmission, which concentrate mainly on the problem of design. The author himself made some contribution to the knowledge of heat transfer and has considerable experience in the design and manufacture of equipment, which he gained as a leader of a development group with Escher Wyss of Zürich.

Part 1 of the book, which comprises roughly half the printed pages, is primarily concerned with the theory of heat transfer and contains design formulæ and

Continued on page 204

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Book Reviews (continued)

diagrams for the estimation of heat-transfer coefficients and pressure drops. This section is somewhat out of balance. It is difficult to see why so much space (over 100 pages) is devoted to boiling and condensing coefficients, which are treated with superfluous thoroughness, whereas forced convection is dismissed in a few pages. The boiling and condensing section is overwhelmed with theoretical details, complicated and lengthy expressions of doubtful validity and usefulness, as, for instance, on the effect of surface roughness on film condensation or the effect of bubble size on the boiling heat-transfer coefficient. It would have been wiser to restrict the theory to a minimum and concentrate on useful correlations and working equations. Perhaps in future editions more attention will be given to the condensation of mixed vapours and condensation in the presence of an inert gas. Part 2 is concerned with mean temperature differences and dirt film factors. Part 3 describes the procedure for an economic design of heat exchanger and Part 4 gives details of construction and mechanical design of standard and less orthodox equipment. Some of the data here are of little interest to British chemical engineers, as they refer to specific codes and standards not applicable to this country. Part 5 deals with the operation of heat exchangers and includes methods of estimating economic cleaning cycles and practical hints on the cleaning of heat exchangers.

The book is well illustrated with diagrams and photographs of full-scale equipment and contains numerous worked examples. Bibliography is excellent and up to date. The text is written for both design engineers and plant personnel, but it should also be useful to students who can benefit particularly from the sections on construction and operation and obtain an insight into the practical aspects of heat-transfer equipment. Although there are numerous and well-established texts on this subject, this book deserves its place as a complementary volume to McAdams and Kern.

T.A.K.

Computers in Purchasing and Stores Departments. Purchasing Officers Association, Queen Victoria Street, London, E.C.4, 1960. 7s. 6d.

THE initiative of the Purchasing Officers Association in running a course early this year on "Application of Computers to Purchasing and Stores Departments" has been matched by their speed in publishing a selection of the papers. The symposium was opened and closed by Mr. J. W. WRIGHT, M.A., Lecturer in Industrial Administration at the Manchester College of Science and Technology. It included a case study on controlling refinery stores by a computer which is used to solve both technical and commercial problems.

Advances in Pest Control Research
Edited by R. L. Metcalf
Volume III, Interscience Publishers Inc., New York, 1960, 448 pp., $14.50.

THIS volume is part of a series. It contains articles on new facets of pest control: eradication of insects by male sterilisation with X- and γ-rays; chemical attraction (followed by destruction) of insects; enhancement of insecticidal activity (of pyrethrins and DDT) by synergists; nematocidal action of organic halides; fungicidal action of dithiocarbamates. It deals also with insect resistance to DDT, absorption and translocation in plant tissue of antibiotics and synthetical agents, and the study of the effect of the pesticides upon radio-labelled biological systems by the labelled pool technique.

This volume should prove of great value to those engaged in pesticide research.

M.P.

SHORTER NOTICES

Guide to U.K.A.E.A. Documents. Edited by J. Roland Smith. Second edition 1960. United Kingdom Atomic Energy Authority. 1s. 6d.

THE GUIDE—now on open sale—explains how the Authority publish information about their research, development, design and other work and where new publications are announced; how the Authority is organised into various autonomous groups, and by which of their establishments information is published; and where the public can obtain free access to read the publications. New features of this edition include details of a sales service of scientific and technical reports, operated by the Authority, whereby the public may place standing orders for those on particular subjects.

U.K.A.E.A. List of Publications Available to the Public. Cumulation No. 4 January-December, 1959, H.M.S.O. 23s.

THE LIST IS classified in broad subject groups—each group consisting of reports and memoranda, translations, periodical articles and books. A final section lists those reports which have appeared in scientific and technical periodicals and books.

Storage of Petroleum Spirit and Petroleum Spirit and Petroleum Mixture. London: 1960. Fire Protection Association. 2s.

THE PETROLEUM (CONSOLIDATION) ACT, 1928, is the principal statutory instrument dealing with petroleum which is defined in the Act as "Crude petroleum, oil made from petroleum, or from coal, shale, peat or other bituminous substances, and other products of petroleum". The conditions of the Act apply to "such petroleum as . . . gives off an inflammable vapour at a temperature of less than 73°F". The definition therefore covers toluene, benzene, n-neptane, n-octane and many other materials. This booklet summarises and discusses the regulations. It also reports on the best practice in storage.

The Engineering Industries in Europe. O.E.E.C., 1959. Obtainable from H.M.S.O. 7s. 6d.

THIS REVIEW opens with brief comments on trends in the engineering industries in 1957 and 1958. They comprise notes on the supply and demand of engineering products and foreign trade in engineering products. Part II consists of statistical information on the European engineering industries covering the engineering industries as a whole or their principal branches. There is no subheading specifically referring to chemical plant or accessories, but some of the tables may be of special interest to chemical engineers for they include pulp and paper-making machinery, sugar-making plant and refrigerating equipment.

Electricity and Productivity Series No. 3, Electric Motors and Controls. First published 1954, reprinted 1959. British Electrical Development Association. 8s. 6d. (9s. including postage).

THIS BOOK IN a series dealing with industrial applications of electricity has two purposes. First, to endeavour to demonstrate how the intensive use of electric motors and controls has helped to raise the productivity of both manufacturing plants and individual machines; secondly, to attempt to give the non-specialist reader an insight into the principles of electric motors and control gear, the variety of types that are available, and how to choose the right motor for a particular drive, then use it effectively.

B.S. 430:1960; Solid Drawn Steel Air Receivers not Intended for Transport. 3s.

THIS CONSTITUTES a second revision of a Standard first published in 1931; the main alteration is an increase in the tensile range of the steels to be used. In it the term "design pressure" is used to denote the values of pressures to be employed for the purpose of calculation. One of a series for air receivers, this Standard applies to solid drawn steel air receivers intended to contain air or inert gas above atmospheric pressure. It is not intended to apply to receivers manufactured from manganese or alloy steels.

Rubber Developments, Vol. 13, No. 1, 1960. National Rubber Development Board, Mark Lane, London, E.C.3.

A NOTEWORTHY FEATURE of this issue is the article on rubber using processing aid 80. This new material is designed to augment the range of available Superior Processing rubbers so that it is now possible to confer superior processing properties on all grades of natural rubber. Since PA 80 is fully compatible with styrene-butadiene rubber, these advantages can be extended to blends of NR and SBR.

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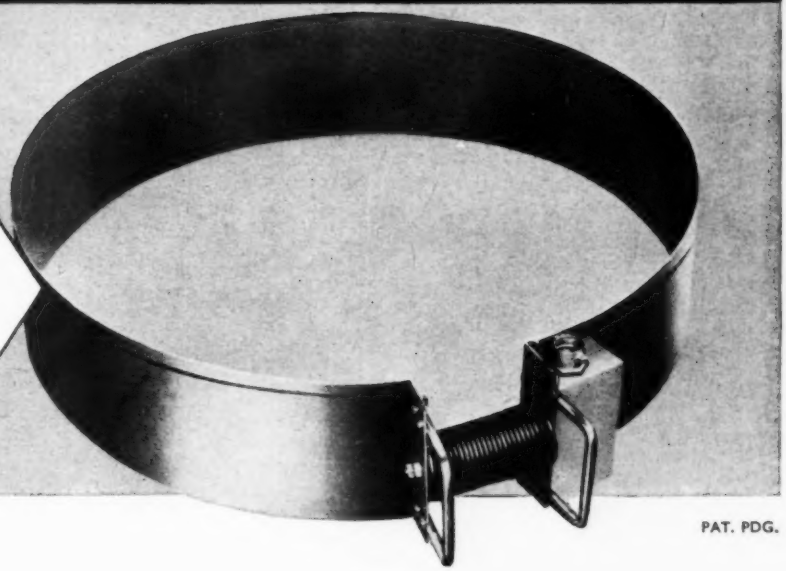

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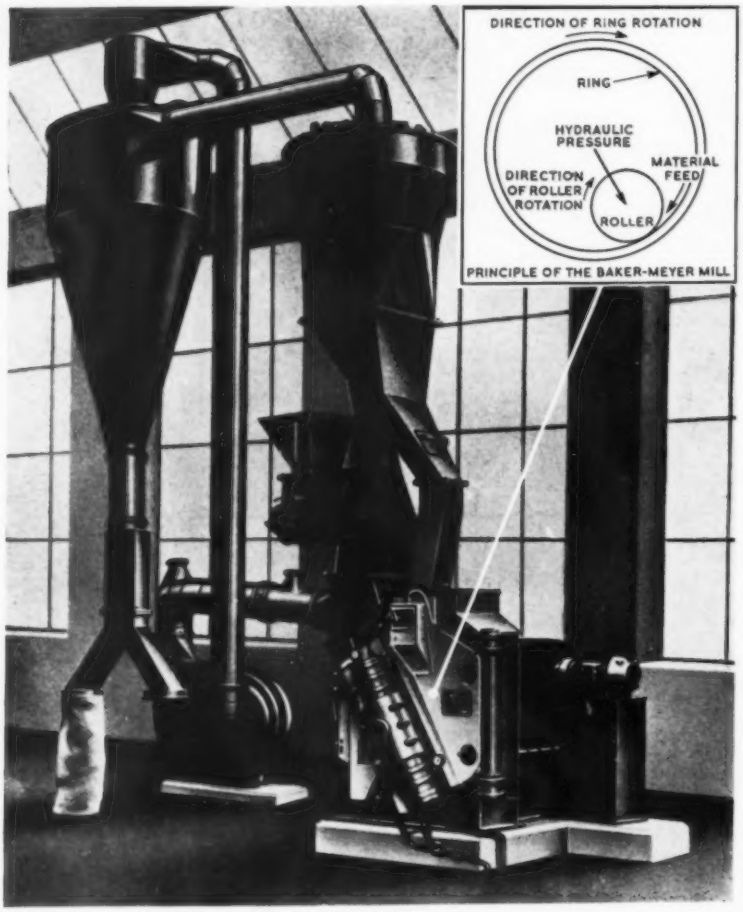
PLANT EQUIPMENT NEWS

Single-roller Mill



A novel feature of a single-roller mill recently introduced into the U.K. is the use of a hydraulic ram to apply pressure between roller and bull ring, a feature which eliminates roller bounce and, at the same time, provides ready adjustment of roller and ring clearance and automatic compensation for wear.

Gases at temperatures as high as 550°C can be used for drying during grinding and feeds containing as much as 25 per cent moisture are easily reduced in size.

The sizes available are five and for a crude feed precrushed below ¼ in. the outputs for a product, 85 per cent of which passes 200 mesh BSS, range from ½-8 tph. All units can produce a product of 99.9 per cent passing a 40-micron sieve.

The machine, the Baker-Meyer Mill, is supplied by **Baker Perkins, Westwood Works, Peterborough.**

BCE 9288 for further information

Data Handling System

Designed to give the greatest flexibility of application and capable of scanning and logging an unlimited number of process variables, the application potential of this system is only limited by the availability of suitable transducers.

An operational accuracy of 0.1 per cent of reading and at speeds in excess of anything previously available with such equipment places this system in the forefront of contemporary data handling equipment.

The standard input is a d.c. voltage or current, and suitable transducers are readily available for applications involving pressure, flow, strain, pulsed and a.c. outputs. Thermocouples or resistance thermometers serve temperature applications, and cold junction compensating units are provided for each type of thermocouple input.

Presentation of information is in digital form throughout. High and low limit checking with alarm indicators, range variations, zero suppression and inbuilt linearisation as required for thermocouples, flow, etc., are available for integration into the scanning sequence. Logging is by electric typewriter on blank or pre-printed log sheets, off-normal points being printed in red. A digital voltmeter is used to measure the process variable and present the result in digital form. Voltages are sequentially switched and compared with the input voltage until a final out-of-balance value within 0.1 per cent is achieved.

The system, including transducers and power supplies, is housed in a cubicle-type panel, the units being rack-mounted for ease of servicing. **Kelvin Hughes Ltd., Livingstone College, Knotts Green, London, E.10.**

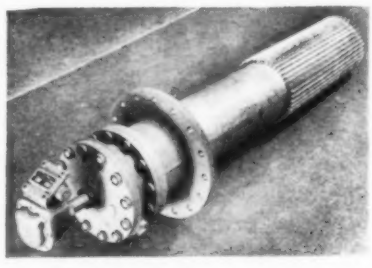
BCE 9289 for further information

Special AEI Flameproof-type Immersion Heater

The immersion heater, rated 15 kW, 415 V, 3 phase, is of unique construction, being designed specially to meet the requirements of a very low heat dissipation. Maximum loading was specified as 4 watts per sq in. of surface, and this was achieved by the use of cast-in elements and exterior finning.

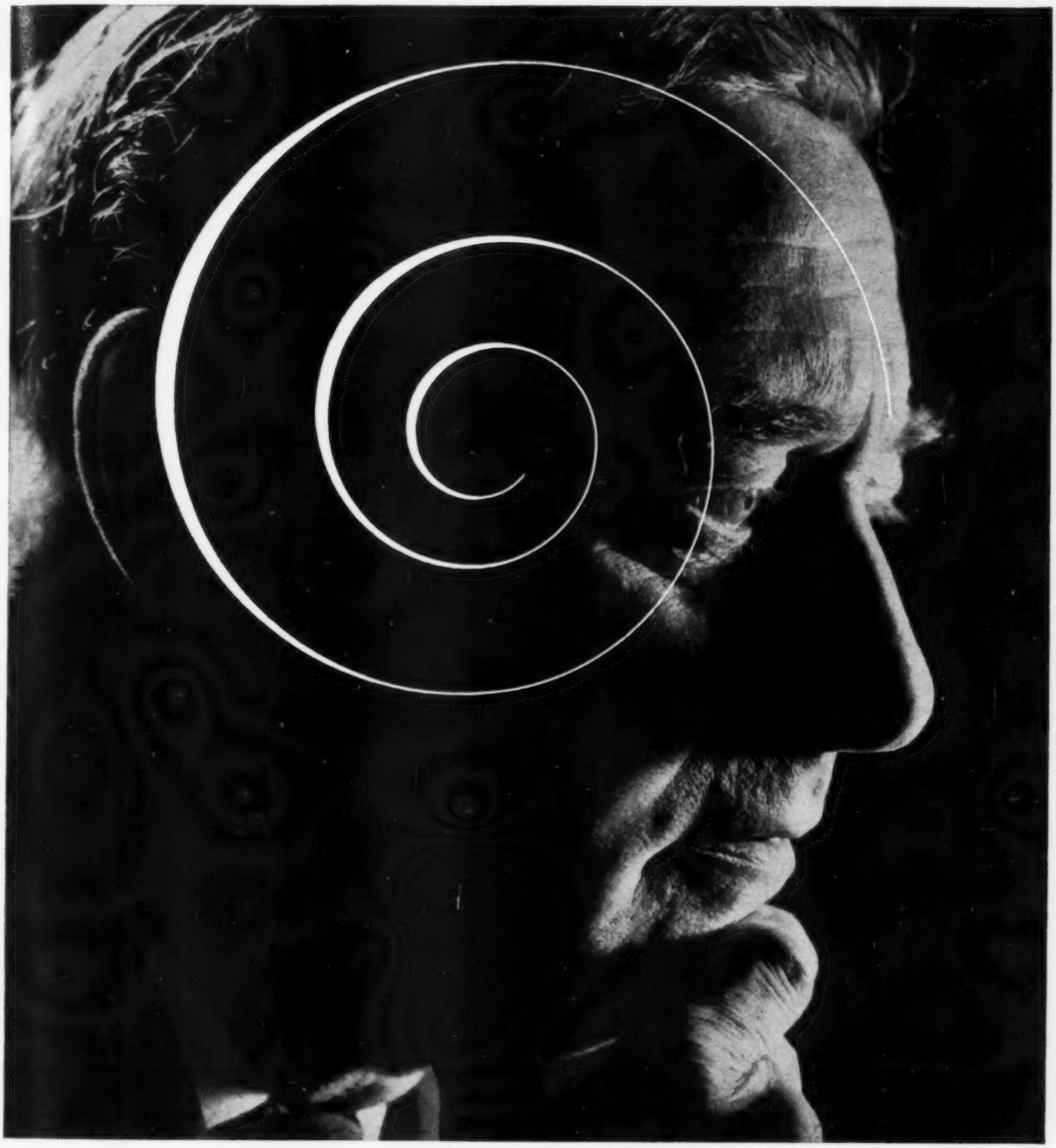
The surface of the heater is coated by a chrome diffusion process to avoid contamination of the liquid to be heated. The thermostat (Maclaren) for temperature control over the 200-300°C range is fitted with a Buxton certified flameproof head, and the heater terminal box is designed in line with Flameproof Specification BS229.

In use, only the finned portion of the unit is heated, the elements being provided with cold extensions. This ensures that, within prescribed limits, a fall in level inside the kettle would not result in decomposition of the liquid around the exposed portion.



AEI Ltd., Transformer Division, Heating and Welding Department, Mosley Road Works, Trafford Park, Manchester, 17.

BCE 9290 for further information



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PLANT EQUIPMENT NEWS

Constant Rate Feeder

The Watson-Marlow C.R.F./J. constant rate feeder is an entirely new means of providing stable feed rates and repeatable doses. It is suitable for use with granules, wet and dry powders, sludges, pastes, minerals and broken solids. Because of its extreme simplicity, versatility, cleanliness and lack of wearing parts, this feeder should find wide application in the chemical industry.

Feeds ranging from a few grains per minute of fine materials up to a ton an hour of heavy materials are obtainable on the one unit. The controls incorporate indicators so that exact settings can be made and repeated at will. It is fitted with an adjustable timer which stops the table at the end of the desired period, and this enables doses of any required volume to be made. The unit is offered with either $\frac{1}{8}$-hp single-phase or $\frac{1}{4}$-hp 3-phase totally-enclosed fan-cooled motors. It measures only $14\frac{3}{8}$ in. to the top of the hopper throat and $16\frac{1}{8}$ in. diam at the base. Its weight is 75 lb net.

Examples of materials handled include wet and dry sands, polythene chips, chocolate paste, fine photographic powders, coal dust, manganese ores and sugar. **The Watson-Marlow Air Pump Co., Marlow, Bucks.**

BCE 9291 for further information

Activated Charcoal Filters

This new range of activated charcoal filters has been designed for use in compressed air systems where oil in the air stream is not acceptable. They effectively remove all traces of oil from the air and also eliminate the associated oil smell.

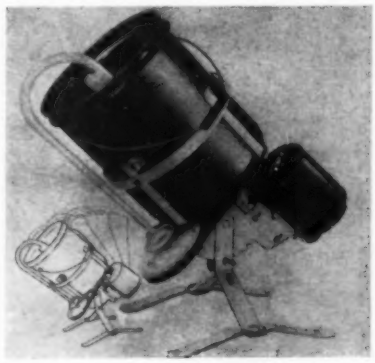
The cartridge of activated charcoal removes oil from the air stream by adsorption and is therefore an expendable item which requires changing at intervals, dependent upon operating conditions. An average normal life of a cartridge element is 1000 to 1500 working hours.

Quick and easy cartridge replacement is one of the key design features. Air inlets are located in the bottom and air outlets at the side of the filters, so that when changing the cartridge it is not necessary to break the air connections. The lid, which is sealed with an "O" ring, is removed, cartridge changed and lid replaced.

Capacities available in the range are 3, 10, 30, 60 and 120 cfm. Illustrated on the left is the 120-cfm model and on the right the 30-cfm model. **Alfred Bullows & Sons Ltd., Long Street, Walsall, Staffs.**

BCE 9292 for further information

Portable Industrial Mixer



This versatile mixer is suitable for practically all materials. It may be used for mixing seeds, paints, powders, resins, plastics, adhesives, printing inks, cosmetics and chemicals to name a few. It will mix an average load of 50 lb (max 70 lb) or $4\frac{1}{2}$ gal and is just right for one-man operation. It is small and easily portable (occupies 2 ft square and weighs 37 lb), easy to clean and costs £24 2s. 0d. **General Trade Equipment Ltd., 82/90 Seymour Place, London, W.1.**

BCE 9293 for further information

Davis Magnetic Tube Tester

This unit is used for determining the magnetic content of ores and is particularly suitable for checking the efficiency of wet magnetic separators recovering magnetite and ferrosilicon in heavy media processes.

The tube tester illustrated consists of an inclined glass tube set between the pointed poles of a powerful electro or permanent magnet. The ore sample is introduced into the water-filled tube and agitated in such a manner as to ensure thorough washing of the arrested magnetics.

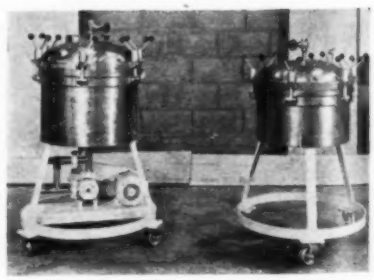
The unit is continuously rated, having a power consumption of 230 watts, motor drive being $\frac{1}{70}$ hp. Overall dimensions are 28 in. × $26\frac{1}{2}$ in. × 12 in. Net weight is 280 lb; gross weight 380 lb. **Rapid Magnetic Ltd., Lombard Street, Birmingham, 12.**

BCE 9294 for further information

Pressure Filters

The Calmic high-duty pressure filter is designed to fulfil the demand for a simply operated, foolproof filter. It is virtually a pressure container mounted on legs and is manufactured as a static model or alternatively on a mobile base on which is housed the motor and pump: a steam jacket can be supplied as an extra. The filter can be operated with wire mesh, cloth, paper or even a combination with filter aids, bleaching earths or carbon, etc. During the filtration cycle, the unit becomes a closed circuit and is therefore ideal for hot or toxic liquids or even those of an inflammable or corrosive nature, where any gas given off would constitute a danger. As the filter plates are in a horizontal position, there is no danger of cake slippage during a run and the filter can be run intermittently, when necesary.

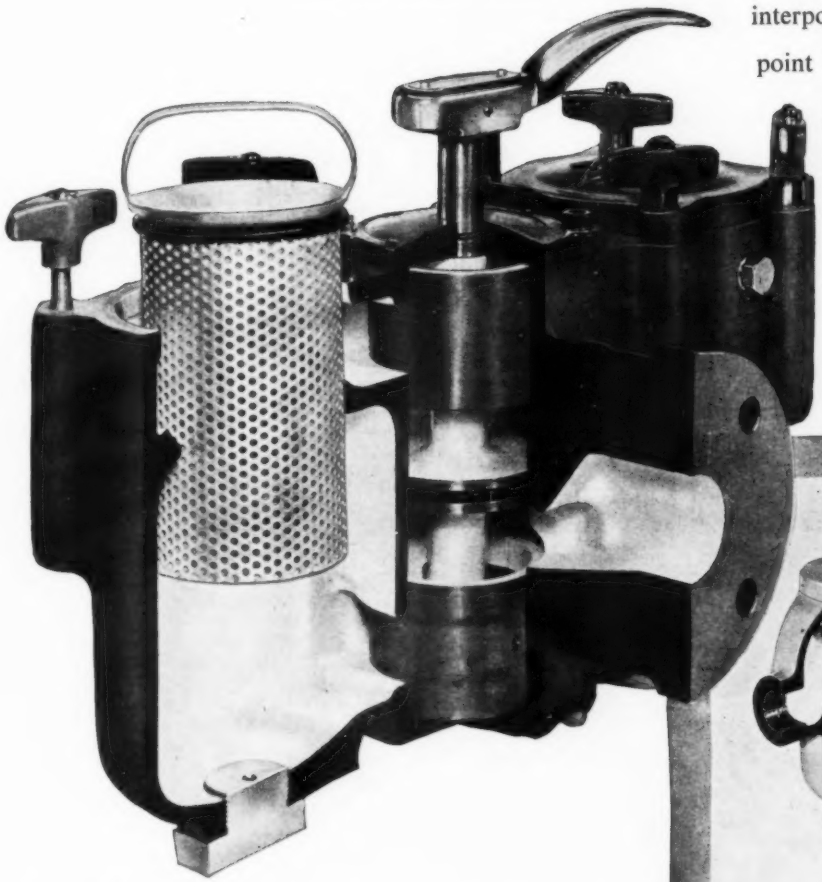
In the general chemical industry Calmic filters are being used for solvent recovery, polishing of disinfectants, collection of solids (within certain limits) in the organic chemical trade, animal and vegetable oils, insecticides, cooling oils where the decolorising process is also practised, dyestuffs and many other processes. Many of these filters are also in use in the paint, varnish and resin industries, and in the pharmaceutical industry. Many of these naturally work at temperatures of 90°C and more with throughputs of 100 gal/sq ft/hr, dropping to the region of 5 gal/sq ft/hr for cold varnishes.



Zwicky PLEX Filters are NEW

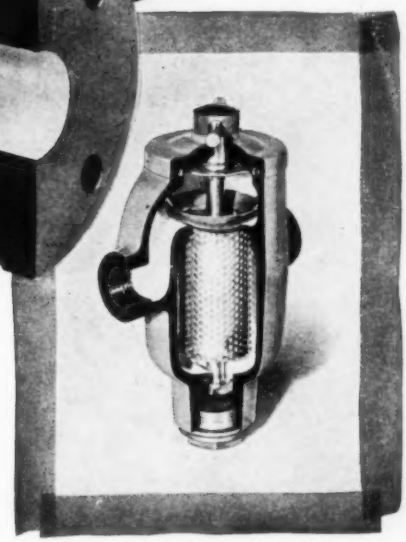
. . . but they are new only in the sense that they are an advanced design of a type of filter unit of which ZWICKY LTD. have many years' design, manufacture *and* operating experience.

The designs of the single-chamber UNIPLEX Filter and the double-chamber BIPLEX Filter represent a distinct advance in the technique of interposing at a pre-determined point in a fluid supply system, an arresting barrier against the passage of undesirable particles of foreign matter suspended in a liquid.



Left: A 2" BIPLEX Filter unit

Below: A 1¼" UNIPLEX Filter unit



This is the booklet in which the UNIPLEX and BIPLEX Filter units are fully described.

Please address enquiries and requests for the UNIPLEX *and* BIPLEX *Filter booklet to:*

ZWICKY LIMITED · Buckingham Avenue,
SLOUGH · BUCKS
TELEPHONE: SLOUGH 21201 TELEGRAMS: ZWIKLIM SLOUGH

PLANT EQUIPMENT NEWS

These filters can quite successfully be used in the cosmetic, brewing, wine and spirit, general food industry and soft drink trades, where, in fact, there are now a few being successfully used; these trades require brilliant "filtrates". **Calmic Engineering Co. Ltd., Crewe, Cheshire.**

BCE 9295 for further information

Corrosion-resistant Epoch Pipe System

Epoch pipe is manufactured from thermosetting epoxide resin, reinforced with high-strength glass and acrylic fibres to give "all-through" corrosion resistance. It will find useful application in the chemical, oil, atomic energy, gas and brewing industries, and also in sewage disposal plants.

Pipe and fittings are available in sizes from 4-15½ in. bore, and can be used in temperatures up to 140°C. They are as strong as steel pressure-pipes, one-quarter the weight and ten times more flexible.

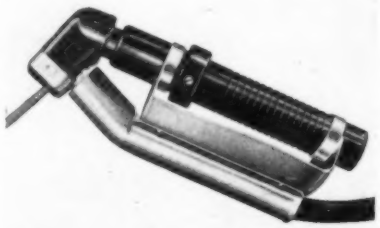
Using mobile bonded jointing equipment based on a Land-Rover, three men can lay 200 ft of pipe an hour.

Standard fittings operate at pressures up to 600 psi, but pipe can be specially manufactured to operate under unlimited pressure. **Bristol Aeroplane Plastics Ltd., Filton House, Bristol.**

BCE 9296 for further information

New Welding Electrode Holder

The new Temer 600 Special electrode holder stays cold during continuous heavy welding. It is specially designed so that the handle remains cold under extreme working conditions, using up to $\frac{5}{16}$-in.-diam electrodes at up to 60 amp. The welding cable is connected direct to the head of the holder, instead of running through the handle in the usual way, and the operator's hand is protected from any heat in the cable by a deflecting aluminium-painted metal shield, under which the cable is housed in asbestos on its way to the head. Price £4 18s. 6d. **Interlas Ltd., 9 Church Street, Ampthill, Bedfordshire.**



BCE 9298 for further information

New Stainless-steel Laboratory Filters

A newly redesigned line of porous stainless immersion tubes, beaker filters and gas dispersion tubes is now available. These units feature type 304 stainless-steel tubes heliarc welded to the centre of type 316 porous stainless-steel filter elements. Elements are dished to a spherical radius.

The filters are available in five porosity grades, with average pore openings of 65, 35, 20, 10 and 5 microns. They can be heated to 400°C without change of weight due to oxidation. Combining light weight and high flow rates with resistance to thermal or mechanical breakage, they are suitable for a variety of laboratory uses.

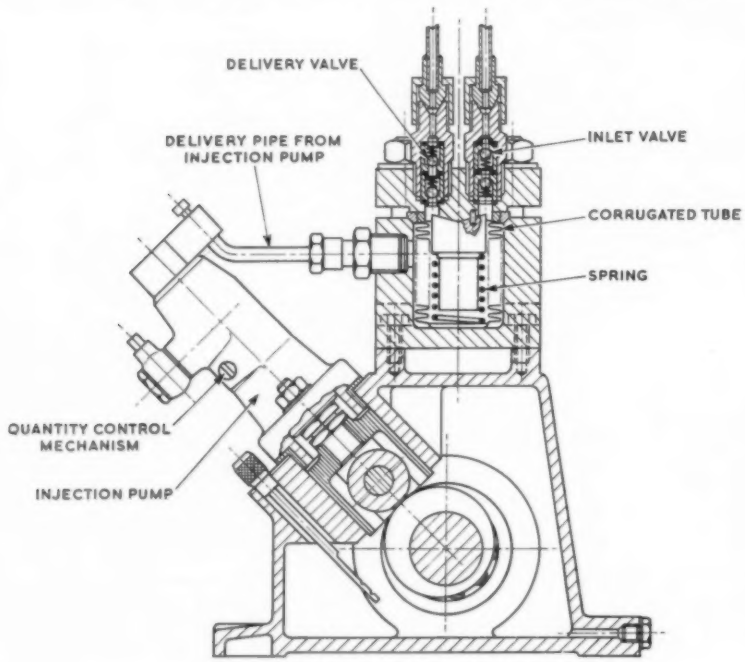
The relative chemical inertness of these units makes them useful with all alkalis, hot or cold, and with most acids. They can be cleaned by backwashing or by chemical treatment. **Pall Corporation, 30 Sea Cliff Avenue, Glen Cove, New York, U.S.A.**

BCE 9299 for further information

Bellows Metering Pump

A stuffing-box-less metering pump, suitable for hot volatile or viscous liquids, employs an internally spring-loaded corrugated bellows, which is alternately compressed and returned to its initial position by the combined action of a variable displacement piston pump which supplies and removes hydraulic fluid from around the exterior of the bellows section, the spring returning the bellows to its original position. The bellows is fitted inside a robust casing at the top of which are attached the inlet and outlet valves of the metering section. These valves admit and discharge the process fluid to and from the interior of the bellows; the latter are available in corrosion-resisting metallic materials. Maximum outputs of this pump, known as the Sigma W-VCH, range from 1.5-800 lit/hr. Pressures generated are 60-320 atm. **Strojexport, Wenceslas Square, Prague, Czechoslovakia.**

BCE 9297 for further information



Gas-tight Control Panels

The recent completion of a number of four-gang and two-gang gas-tight control panels, which are intended for use where radioactive atmospheres, gases and fumes are to be excluded from the control side of switch panels, is announced by J. R. Ferguson Ltd.

These panels are of 15 amp capacity, and the gas-tight feature is obtained by the use of Ethox epoxide resin mouldings, in which components from standard 15-amp plugs and sockets are employed.

The remarkable adhesion of epoxide resin to metal conductors means that it is virtually impossible for radioactive atmospheres and gases to percolate along the conductor lengths.

The chemical resistance of Ethox epoxide also makes these control panels useful in chemical plants. **J. R. Ferguson (Electrical Engineers) Ltd., Tameside Works, Park Road, Dukinfield, Cheshire.**

BCE 9300 for further information

Veriflux Amplifier

A new amplifier known as the Veriflux, for use with the Altoflux flowmeter, has recently been introduced. One of its features is the facility to feed the output directly into any proprietary secondary instrument such as potentiometric and deflection types or electronic transducers.

There are two outputs of 0-15 mA and 0-50 mV and printed-circuit construction is used throughout. An indicating milliameter to facilitate setting-up and check calibration is incorporated. The standard

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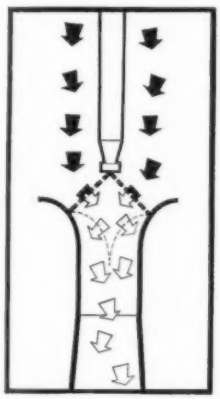
to really efficient gas cleaning



In the Ambuco venturi scrubber, made under licence from Waagner-Biro, the gases are compelled to pass through *two* complete cones of water. This exclusive feature guarantees up to 99·6% collection efficiency of most entrained solids in the range 5 to 0·01 microns.

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PLANT EQUIPMENT NEWS

amplifier is suitable for three flow ranges and the instrument is completely interchangeable with the present Autoflux amplifier. **Alto Instruments (G.B.) Ltd., Bath Road, Stroud, Glos.**

BCE 9301 for further information

New Fibre Drum for Liquid Packaging

This is the latest addition to the recently announced range of Venesta lightweight low-cost containers. The new 5-gal liquid-carrying fibre drum may be fitted with polyethylene, pvc or rubber latex flexible liner. It features a novel method of seaming on the metal ends which leaves the interior completely free from projections. The retractable pouring spout illustrated is a standard fitting with the latex liner; optional with polyethylene or pvc. **Venesta Plywood Ltd., Vintry House, Queen Street Place, London, E.C.4.**

BCE 9302 for further information

New Powder Weld Torch

A new powder weld process for depositing Deloro Stellite heat-, abrasion- and corrosion-resistant hard-facing powder alloys is now available. It is claimed to be twice as fast as arc, simple and easy to operate, and spraying and fusing are in one operation. Typical powder weld applications are as follows: shear blades, textile blades, wear blades, normal and integral valve seats and conveyor screw flights. The Model 50 Schori Pistol, incorporating the powder weld adaptor is illustrated. The system uses acetylene, oxygen and argon. **Deloro Stellite Ltd., Highlands Road, Shirley, Solihull, Warwickshire.**

BCE 9303 for further information

New Air Dryer

Only recently introduced into this country from the United States, the Budget dryer B-6-A was developed by the McGraw-Edison Co.

It is tailor-made for applications requiring very dry air in small quantities, up to 20 cfm, and will dry other gases too. A constant flow of dry air can be supplied to instrument controls, wave guides, small cubicles and other equipment. It is portable—weighs only 70 lb—and thus is especially suitable for pilot-plant operations. It is not affected by variations in air pressure. **G.W.B. Furnaces Ltd., Dudley, Worcs.**

BCE 9304 for further information

Self-baking Liquid Tile

This "Liquid Tile" coating, developed in the United States, was used to coat certain areas in the Bradwell nuclear installation as a protection against radioactive contamination. It will stand 10^9 times a lethal dose of radiation, and can be decontaminated of fissionable material with simple soap and water.

It is applied by brush, spray or roller directly to the sub-surface and sets to a tile-hard inner finish by chemical heat, generated by a catalyst which is added to the material before use.

Having no joints, it produces the ideal coating for chemical manufacturing plants. It is very resistant—boiling sulphuric acid does not affect it—and it contains no solvents. **Acalor (1948) Ltd., Crawley, Sussex.**

BCE 9305 for further information

Miniature Force Balance System

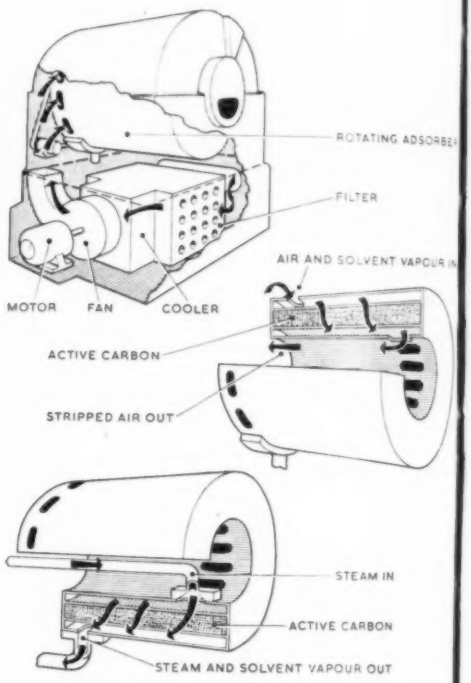
This is a versatile pressure transducer in which the capsule output force is balanced by a precision spring and servo-driven lead screw. The rotation of the lead screw is a direct function of pressure change, and can be made to operate dials, counters, remote indicating transmitters, computers or digitisers.

By way of example, a remote indicating instrument was exhibited at the *45th Physical Society Exhibition 1961*, which has a range of 0-800 mm Hg absolute, with an accuracy of 0.25 per cent, using a two-pointer indication, each rotation of the "fine" pointer representing 100 mg Hg. The system can readily be adapted to differential pressure measurement. **Kelvin Hughes Ltd., Livingstone College, Knotts Green, London, E.10.**

BCE 9306 for further information

Continuous Solvent Recovery Plant

In this continuous unit solvent-laden air is filtered first to remove dust and heated or cooled to a definite temperature before being fed through the active carbon bed within the adsorber. The latter rotates continuously; its carbon is automatically steamed and the vapours thus produced conveyed to a condenser. The condensed steam and solvent is collected in a pressure seal tank and in the case of solvents immiscible in water the tank is constructed to act as a separator.



A feature of this equipment is that it is housed within a single casing. Various capacities are available for a wide range of duties. **Sutcliffe, Speakman & Co. Ltd., Leigh, Lancs.**

BCE 9307 for further information

Mechanical Seal

The value of a mechanical seal that can run dry continuously without overheating needs little emphasis since there are few instances where pumps and compressors do not have some periods of dry running. A seal of this kind would have many applications where temperature rise at the seal faces occurs or where power absorption is important. Duties such as the lifting of volatile liquids are appropriate applications for such a seal.

A seal with these characteristics, "J6", has been marketed recently by Cannings and it can be supplied for external or internal fitting as a self-contained unit

BCE 9247 for further information

BEVERLEY *turbofin* HEAT UNIT

— has no equal for temperatures up to 400°C

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Organic—Inorganic—Acid or Alkali
any of which can contain solids,
FOR DISTILLATION & CONCENTRATION ETC.

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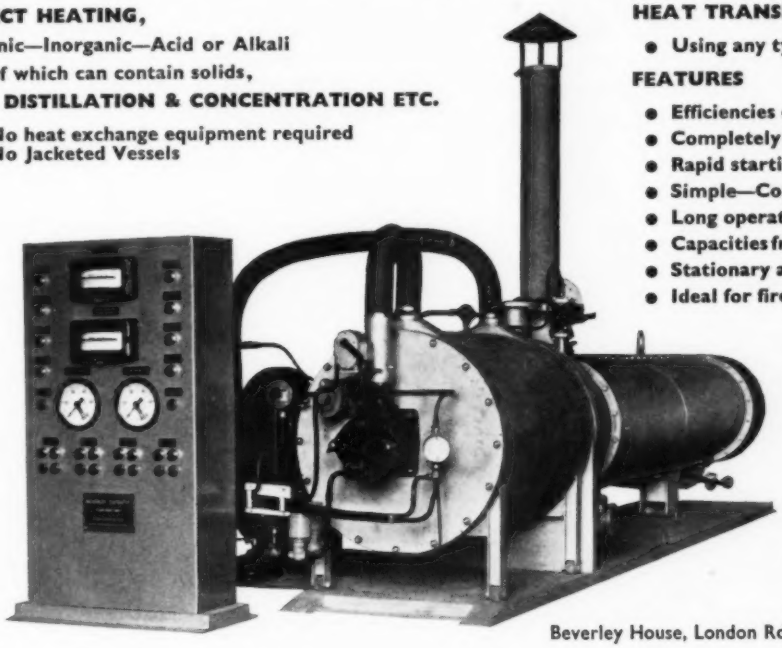

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BCE 9248 for further information

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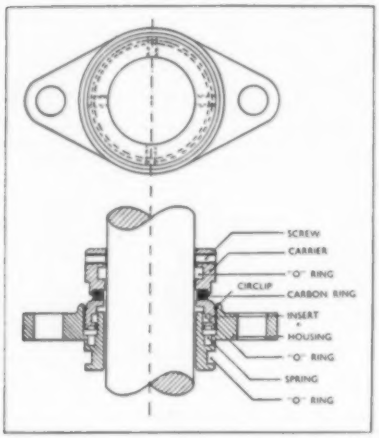


requiring neither cooling nor lubricating. It is capable of withstanding speeds up to 3000 fpm. **J. A. Cannings Ltd., Bathwick, Bath, Somerset.**

BCE 9308 for further information

Metering Pump

This pump, known as the Tolu feeder, consists of two diaphragm units which work independently of each other. The diaphragms and check valves operate in transparent plastic housings and can, therefore, be observed during operation. The output from each unit is easily adjusted by means of a milled knob and scale while the pump is running. Capacity ranges from ½-7 gph for each unit.

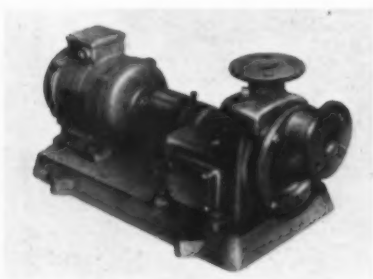
Apart from the plastic housings, the other material used in the construction is stainless steel, but other special materials can be used if required.

Price of a single unit is £110 and a double unit £175, these being complete with ¼-hp gear motor. **Neldco Processes Ltd., Crossway House, Bracknell, Berks.**

BCE 9309 for further information

New Self-priming Centrifugal

The main features of a new pump for the process industries are self-priming ability, absence of valves and close working clearances. The volute priming chamber and bearing housing with fixed feet are cast in one piece, thus reducing the number of liquid joints to a minimum. Mechanical seals of various types can be fitted, according to whether the liquid to be pumped is a solvent, an acid or other aggressive solution.



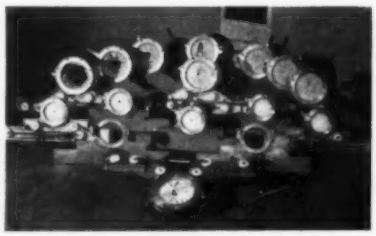
The impeller will tolerate particles in suspension and both it and the mechanical seal are easily reached from the volute end cover.

Normal materials of construction are stainless steel or other resistant alloys. It can also be supplied in cast iron or gunmetal. The type known as the 1AS 51 has a capacity of 1550 gph at a head of 5 ft and 350 gph at 60-ft head. Motor speed is 2850 rpm and its h.p. is 1. **Girdlestone Pumps, Woodbridge, Suffolk.**

BCE 9310 for further information

Valves for Solids

The principal applications of a special flexible sleeve valve which can function as a variable orifice include the discharge of solids from hoppers, mixing machines, conical blenders, dust extraction plant, as well as for weighing machines. Provided the correct valve sleeve combination is used, valves of this kind will control and seal the flow of all solids whether they are lumpy materials, chips, tablets, granules or very fine powders. They will also control the flow of air, liquids and slurries.



These valves, which are now available in a much extended range, are made in five main models, depending on the duty. Thus, the series "A" heavy-duty single valve, in sizes up to 18 in. bore, is suitable for solids standing on 150 mesh, for air and for slurries.

Various materials can be used for the sleeve, such as nylon, terylene, neoprene, linatex or rubber. **Mucon Engineering Co. Ltd., Stonefield Way, South Ruislip, Middx.**

BCE 9311 for further information

Versatile Gas Turbine

Suitability as a prime mover for pumps, compressor sets, package power plant and with process applications typify the recently-introduced Mars gas turbine.

From an operating point of view, the advantages of this gas turbine are that it is air-cooled, is easy to hand start, will accept full load when rated speed is attained, all in a matter of seconds, and will burn a variety of fuels without loss of performance. Again, the fuels normally used, such as paraffin, are cheaper and are untaxed for industrial purposes.

The engine is rated at 50 hp operating at 40,000 rpm, and with gearbox and accessories weighs no more than 98 lb. Output speed is approximately 4400 rpm. It will drive a pump delivering 500 gpm at 100 psig. Compressors of the rotary type, when driven by it, will deliver up to 200 cfm at 100 psig. It is worth noting in connection with process applications that, in addition to developing 50 shp, it will provide heat up to 500,000 Btu/h. **Perkins Gas Turbines Ltd. (Dept. T.1), Peterborough.**

BCE 9312 for further information

New Publications

Uses of Nitrile Rubber

Applications of nitrile oil-resistant rubbers in nine different industries are featured in "The Hycar Rubber Story", a well-produced 20-page booklet. The special properties of Hycar butadiene-acrylonitrile rubbers and latices are summarised, and a pictorial description given of methods of processing. The engineering applications illustrated include machine mountings, oil seals and Hycar-metal laminates for use as gaskets. For the transport industry, fuel hoses, collapsible containers, brake linings and windscreen-wiper blades are featured. In the adhesive industry, many industrial and domestic formulations are based on nitrile rubbers. Illustrations show a well-known brand of children's shoe which uses Hycar for the soles; the stiletto heel tips of ladies' shoes are also moulded from a blend which includes nitrile rubber. Further examples of this material's increasing application are given from the aircraft, printing, textile, leather and paper industries. — **British Geon Ltd., Devonshire House, Piccadilly, London, W.1.**

BCE 9313 for further information

"Gas-Stat" Controllers

These temperature controllers, described in a 4-page leaflet, No. R/42, regulate the supply of gas to a burner according to the temperature in the heated system. The temperature detector is a mercury-in-steel Bourdon-tube system; this regulates a valve in the heating-gas supply. The supply temperature may be recorded by a pen on a circular chart or, in indicating controllers, displayed by a meter.— **Negretti & Zambra Ltd., 122 Regent Street, London, W.1.**

BCE 9314 for further information

Instrumentation Contract Engineering

The services of the Contract Engineering Division are featured in a 12-page brochure, No. C100. Details are given of three standard types of instrument panel—"Lockmet", "Lockplast" and "Ultimet"—for which no drawings are required except for the size and positions of cut-outs, etc. Typical panels, supplied to various industries, are illustrated.— **Negretti & Zambra Ltd., 122 Regent Street, London, W.1.**

BCE 9315 for further information

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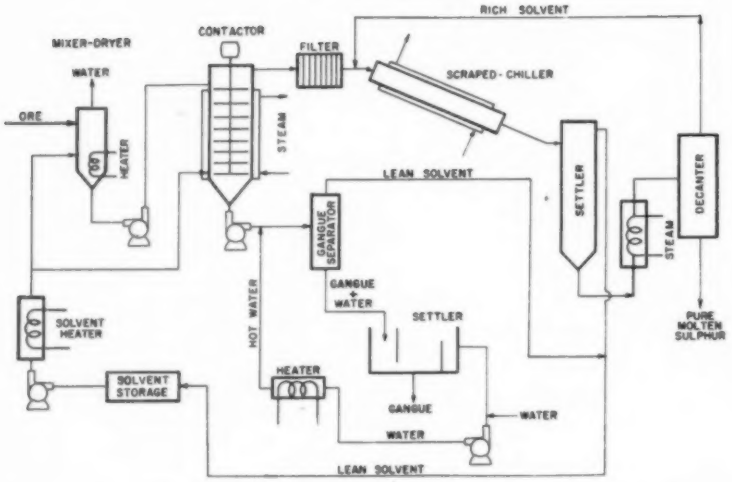
New Processes



New Sulphur Extraction Process

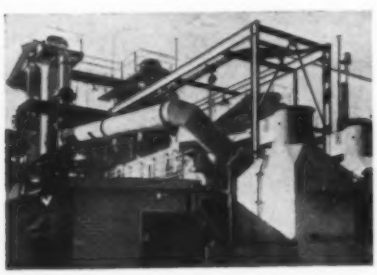
A solvent extraction process for the recovery of elemental sulphur from ores, which offers economic and technical advantages, has been patented by Delhi-Taylor Oil Corporation, of Texas, U.S.A.

Elemental sulphur is dissolved out of the native ore in a mixer-dryer unit, using as solvent a diesel fuel (b.p. 400-600°F). By keeping the temperature at 250°F, dehydration of the slurry is ensured. A second stream of lean solvent meets the slurry in a steam-jacketed contactor unit to dissolve any solid sulphur remaining.

Crystalline sulphur is precipitated from the solvent in a water-cooled unit at about 70-90°F. Solubility of sulphur in the diesel grade solvent employed is about 10 per cent by weight at 250°F and thus the best ratio is 15:1 oil to sulphur.

Dehydration of Town Gas by Refrigeration

The dehydration of town gas before distribution is often achieved by utilising calcium chloride as the drying agent. A new method of dehydration involves cooling the gas by direct contact with the coils of a refrigerator evaporator. This plant, designed by Woodall-Duckham and W. C. Holmes & Co. Ltd. and constructed in Australia, handles two independent low-pressure gas streams each of 4 million cu ft per day. The gas may enter the plant at 100°F, saturated, in the summer and at about 70°F at other times of the year. It is cooled to about 75°F in a heat exchanger using cold gas leaving the refrigerator section. It is cooled to its required dewpoint temperature by passing through the final cooler. In the picture of the refrigerant gas dehydration plants at East Perth gasworks, the atmospheric ammonia refrigerant coolers can be seen in the foreground. On the roof are the refrigerant gas cooling tunnels, and the heat exchangers and direct contact cooling towers are in the background.



The hydrogenation of brown coal by the fluidised-bed process is being carried out in a pilot plant designed and installed by Australian chemical engineers of the C.S.I.R.O. The plant employs countercurrent contact between coal and hydrogen-rich gas in a 20-ft-deep baffled fluidised bed.

Coated particle nuclear fuel concept is the subject of a three-year U.S.A.E.C. research programme contract assigned to Battelle Memorial Institute, Ohio. The object of this programme is to develop coated particles with high-temperature properties, fission product retention capability and good neutron economy. In this process small grains of the fissionable nuclear fuel compound are coated individually with a dense, refractory material that will both protect the fuel from damage by chemical reaction at the high temperatures of the nuclear reactor, and prevent escape of the troublesome radioactive by-products formed in the fuel by the fission process. In early tests both carbon and alumina coatings have worked well. Manufacturers interested in this concept should contact DR. R. W. DAYTON at the Institute for information about the evaluation programme.

Aerojet-General Corporation has experimentally transformed ammonia into hydrazine through atomic radiation. Hydrazine can be produced for about 25 cents a lb through the new method on a full-scale basis, compared with an estimated cost of $1.65 a lb when made by conventional chemical techniques. Four or five years will be needed to have a plant in operation. Hydrazine is a powerful and attractive rocket fuel because it can be stored, and will not explode in the event of a launching mishap.

Poison-free gas is to be supplied to households in Munich from projected converter installations, which will reduce the lethal carbon monoxide content of coal gas to 2 per cent. Since 1957 there have been nearly 200 accidental deaths from gas poisoning in Munich.

Five saline water conversion demonstration plants are under construction in various parts of the U.S.A. The first is a twelve-effect, long-tube, falling-film evaporator distillation plant for the production of one million gal per day of potable water from sea water. The second is a multi-stage flash evaporator plant consisting of 36 stages for the production of one million gal. per day. Another is a water treatment plant utilising the electro-dialysis process to demineralise 1800 ppm brackish water in order to produce 250,000 gpd of fresh water. The fourth is a forced-circulation vapour compression distillation plant to produce one million gal. per day of demineralised water from brackish water, and the last is a freezing process plant to produce 250,000 gpd of potable water from sea water.

Desalination of sea water at a cost of about 8s. per 1000 gal could be achieved with present-day technology, say Australian chemical engineers of C.S.I.R.O. It would be carried out in very large plants with outputs in excess of 40 million gal per day together with by-product electricity, and using nuclear reactors as the heat source.

Company News

Industrial & Trade Fairs Ltd. (jointly owned by George Newnes Ltd. and the Financial Times Ltd.) have acquired, with Beck & Pollitzer Ltd., the whole of the

BCE 9250 for further information

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share capital of the old-established business of F. W. Bridges & Sons Ltd., exhibition organisers of the Engineering, Marine, Welding & Nuclear Energy Exhibition, the International Printing Machinery & Allied Trades' Exhibition, the Chemical & Petroleum Engineering Exhibition, The Laundry, Dry Cleaning & Allied Trades Exhibition, etc. A new holding company has been formed under the title of Bridges Exhibitions Ltd.

Corrosion & Welding Engineering Ltd. is the name of a new company formed by the amalgamation of Welding Supervision Ltd. and Cathodic Corrosion Control Ltd. (wholly-owned subsidiaries of Constructors John Brown Ltd.). The new company will provide all the services previously performed by the two subsidiaries.

Faserwerke Hüls G.m.b.H. is the name of a joint enterprise established by Chemische Werke Hüls A.G. and by the Tennessee Eastman Co. (U.S.A.) to produce and sell a polyester fibre in the growing European textile market. The fibre will eventually be produced in a new factory now under construction at Marl, in the north of the Ruhr area.

The Société de la Raffinerie de Strasbourg S.A. has been formed to build a refinery at Herrlisheim, about 15 miles north of Strasbourg. It is designed to supply the North-east French, South German and Swiss marketing areas. The refinery capacity will be about 3.3 million tons a year and it is expected to be commissioned early in 1963.

The Société de la Raffinerie d'Alger has been formed to construct a 2.5 million tons a year refinery at Maison Carree near Algiers. The refinery will be of a "simple" design comprising an atmospheric distillation unit and a catalytic reformer to process Hassi Messaoud crude and Hassi R'mel condensate in order to meet the main product requirements of the expanding Algerian market. The estimated cost of the refinery is £17 million, and it is expected to come on stream early in 1963.

Petro Engineering Services Ltd. is the name of a new company formed to give a service to industry in the design, purchase, manufacture and direction of petrochemical and medium to heavy engineering plant.

Recent Conferences

The 44th National Meeting of the A.I.Ch.E. followed the lines of similar previous events and a total of 116 papers, covering a wide range of subject-matter, was presented. Unlike previous meetings, this one was accompanied by a petrochemical and refining exposition which displayed equipment from something like a hundred firms. Other events were the works visits which took in such plants as that of Monsanto at Luling, Shell Chemical at Norco, Solvay at Baton Rouge, Ethyl Corporation (Baton Rouge), The Keiser Aluminium & Chemical Corporation (Chalmette), and many others. As is customary with these meetings, the papers presented covered a very wide range, a few of which will be touched upon here.

In the field of mass transfer, VERMEULEN (Paper 68) recorrelated published performance data for packed and spray extraction columns and provided an improved basis for the design and scale-up of equipment of this type: he discussed the effect of residence time and interfacial area. TREYBAL (Paper 69) examined critically existing correlations for liquid extraction carried out in stirred tanks and mixers and discussed such design features as impeller type and size, jet injectors, orifices and valves when used as mixers. STRAND (Paper 70) discussed scale-up procedures for RDC liquid extraction columns and RICHARDSON (Paper 71) dealt with the design, development and pulse columns for the Purex process for irradiated nuclear fuels.

Filtration was the subject of a number of papers. Thus, JAHREIS (Paper 84) showed how to calculate filtration constants under plant conditions and he gave a method of estimating them without interfering with plant operation or layout. The behaviour of a mixture of two slurries was considered by SHIRATO (Paper 85) which he correlated with the filtration characteristics of the mixture he used.

Apart from RUBIN (Paper 91) and MOORE (Paper 94), optimisation did not receive a great deal of attention. RUBIN dealt with the determining of the initial conditions of a process that optimised functions of the system variables at a given position or time. MOORE, whose paper was primarily concerned with computer programmes and techniques, described experiences of process simulation problems and the compiling of matrices suitable for optimisation calculations.

The solution of rigorous absorber calculations by means of a small digital computer was demonstrated by MCNEESE (Paper 92). He used what he termed speed-fixed point arithmetic to solve a multi-component hydrocarbon absorber problem.

Mathematics formed the basis of a number of specialised papers. Of these may be mentioned a review of the mathematical tools required for studying process dynamics and control. In this paper (No. 109) SCHNELLE discusses linearisation methods, the Laplace transform-transfer concept and the use of the Nyquist and other plots. Such techniques, properly applied, help to make plants economical. ROSENBERG (Paper 111) offered numerical solution methods for partial differential equations representing fixed-bed reactions.

Contracts

Andrew Crookston & Co. Ltd., in association with L. H. Manderstam & Partners, have been awarded, by the Five-year Plan Organisation of the U.A.R., a contract for the investigation into the industrial application of electric power which will become available from the High Dam. The study will include the following industries: phosphorous and phosphoric acid; aluminium; nitrogenous fertilisers based on electrolytic hydrogen; electrolytic caustic soda with special emphasis on the utilisation of the chlorine produced; and silicon carbide.

Continued on page 220

Personalities in the News

Sir Cyril Hinshelwood, O.M., F.R.S., who retired as President of The Royal Society in November last, has been awarded the Royal Society's new Tercentenary gold medal for his outstanding contributions to physical chemistry. The medal is to be awarded by the Society every three years to the individual who, in the opinion of its Council, shall have made the most significant contribution in the field of pure or applied chemistry or engineering including chemical engineering. The medal will be accompanied by a monetary award of £500.

Mr. J. Arthur Reavell, chairman of the Kestner Evaporator & Engineering Co. Ltd. and the Kestner Group of Companies, retired from the chair on December 31, 1960, after 53 years with the company, and assumed the appointment as the company's first president. The new chairman is MR. B. N. REAVELL and the new managing director is MR. G. H. BLACK.

Dr. I. Berkovitch, formerly Associate Editor of this journal, has been appointed the new chief chemist for Polycell Products Ltd.

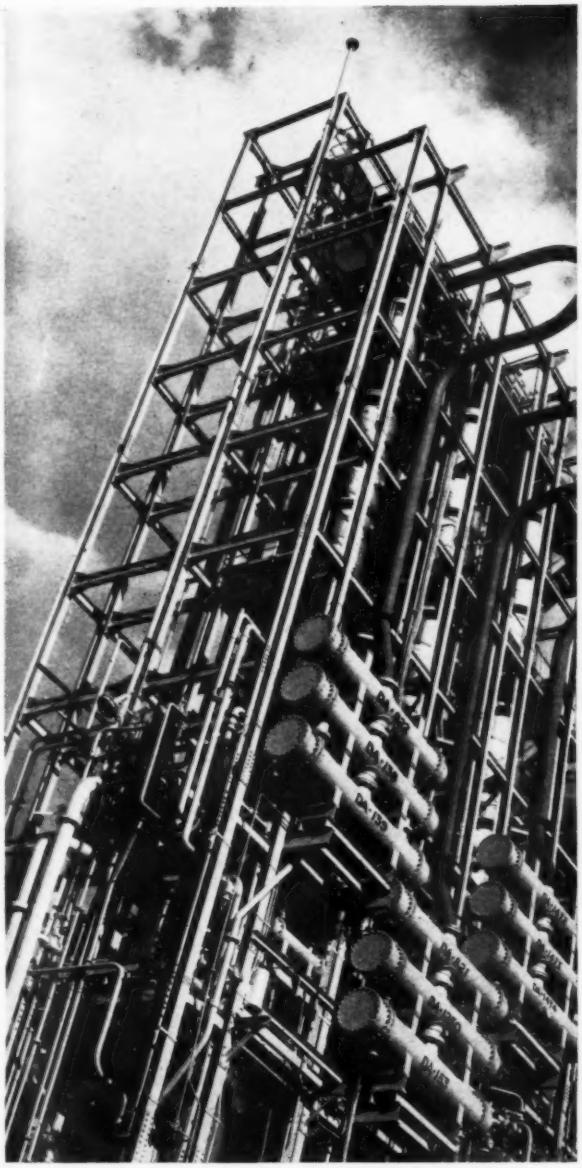
Dr. P. H. Sykes, Director of Research and Development of the Reed Paper Group, has been appointed deputy managing director of Albert E. Reed & Co. Ltd. In order to take up his appointment with Reed in 1958, DR. SYKES resigned his position as technical and research director of the British Oxygen Group of Companies.

Monsanto Chemicals Ltd. have appointed one of their technical staff, DR. I. S. WILSON, to the newly created position of senior scientist. This appointment is part of a scheme under which outstanding scientists on the company's staff may receive proper recognition of their status while continuing to specialise in scientific or technical work.

The A.P.V. Co. Ltd. announce that as from January 1, 1961, MR. P. W. SELIGMAN has been appointed deputy chairman, while retaining his present position of managing director, and MR. H. P. M. BENSON has also been appointed managing director.

Mr D. T. Barrett has been appointed deputy chairman of Simon Engineering Ltd. with effect from January 9, 1961.

BCE 9251 for further information



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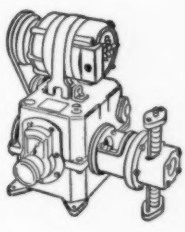


Metering Pumps Limited, 21, The Mall, Ealing, London, W.5
Telephone: EALing 6264 (PBX)

Whessoe Ltd., of Darlington, have been awarded a contract for the supply and erection, in Upper Assam, of plant required to condition crude oil before it is pumped through the 720-mile-long pipeline from the Nahorkatiya Oilfield to the new oil refineries at Nunmati and Barauni. The contract, valued at nearly £1 million, was awarded by Oil India Ltd.

Lodge-Cottrell Ltd., a subsidiary of Simon Engineering, are to supply an £85,000 gas cleaning plant for two sinter machines to the Anglo-American Corporation of South Africa. The plant consists of two sets of evaporative cooling equipment with pumps; sprays and valves; two precipitator units of the three-stage horizontal flow type; and H.T. transformer-rectifier equipment.

Another Lodge-Cottrell contract is to supply two precipitator units of the three-stage horizontal flow type for the separation of carbon black from a cracking gas, to be erected at Halinogorsk (U.S.S.R.).

Parsons Powergas have received an order from the H. K. Ferguson Co. to design, engineer and supply a sulphur recovery unit for Argentina. The plant handles an acid feed gas and will produce 42 long tons per day.

A.E.I. Ltd. have secured a £750,000 electrical equipment contract for a new polyolefine plant being constructed by Matthew Hall & Co. Ltd. and George Wimpey & Co. Ltd. for the Shell Chemical Co. Ltd. at Carrington. This plant is planned to produce 30,000 tons of low-density and high-density polyethylene and polypropylene per annum.

Another A.E.I. electrical equipment contract is for a new chemical plant to be built at the Fawley refinery of Esso Petroleum Co. Ltd. This plant is for the production of ethylene which will be piped direct to the new Severn Side works of I.C.I. Ltd. The contract includes a 13,000-hp motor for a compressor drive, which is understood to be the largest direct-on-line started squirrel-cage motor to be used in a refinery process anywhere in the world.

Humphreys & Glasgow Ltd. have received a contract worth £1¼ million for the design and construction of a chemical plant in India. It will produce chemical products based on naphthalene and is to be built for Atul Products Ltd. at Bulsar, 120 miles from Bombay.

British Oil Equipment Credits Ltd. announces that a second financing agreement has been entered into and ratified with Petroleos Mexicanos.

George Kent Ltd. recently supplied the largest single section instrument and automatic control panel ever manufactured by the company to the order of Babcock & Wilcox Ltd. for the South African Electricity Supply Commission's Hex River Power Station.

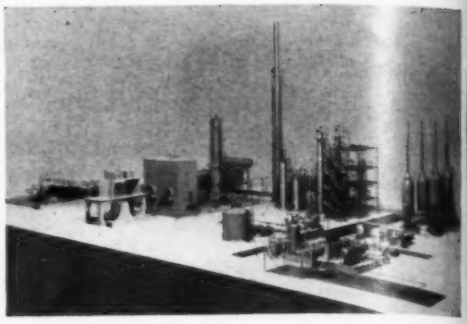
New Plants in Brief

New installations of Chemische Werke Hüls AG in 1960 include erection of a wet phase carbon black production unit, automation of the plasticised production, the pelleting of SK resin, hydrochloride production under pressure, expansion of the marpholine production and of P.V.C. paste output to 400 tons/month, and the extension of the pipeline system to Leverkusen. Other expansion projects of Chemische Werke Hüls include a new acetic acid plant based on butane, enlarged acetylene capacity achieved by the erection of a new gas compressor, and provision for increases in the production of croton aldehyde and phthalic anhydride.

The A.P.V. Co. Ltd. have recently supplied and erected West plate distillation equipment for the third-stage extensions to I.C.I.'s silicones plant at Ardeer, Scotland. A.P.V. have also been asked to supply a methyl chloride vaporiser, several more West distillation and recovery columns with condensers and reboilers, and a reaction scrubbing column.

Polyethylene production facilities at the Fawley factory of Monsanto Chemicals Ltd. are to be further expanded. Original capacity was 10,000 tons a year and by 1963 it will be in excess of 17,000 tons a year.

Werkspoor N.V.-Amsterdam are constructing a plant at Lissabon for the production of 380 metric tons/day of 54 per cent nitric acid. The absorption process takes place at 42 psi.



A Texaco partial oxidation gasification plant is being designed and supplied by P.G. Engineering Ltd. for Fertilisers & Chemicals (Travancore) Ltd., South India. The plant, which will produce carbon monoxide and hydrogen, also includes process units for high-pressure carbon monoxide conversion, and the removal of carbon dioxide and residual hydrogen sulphide by water scrubbing. Initially, the plant will process naphtha, but is laid out so that if fuel oil is to be used the additional acid gas purification plant can be added. An interesting feature of this plant is that carbon produced in the Texaco generator is recovered and recycled. A model of the plant is illustrated above.

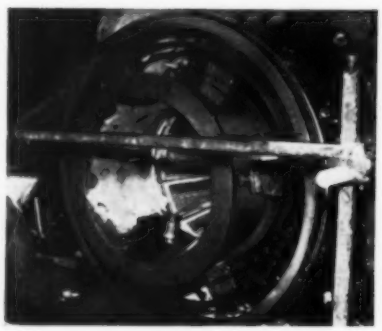
Sasol's £30 million expansion programme announced recently will include a plant for the production of nitrogenous fertiliser materials. Sasol has abundant ammonia and nitrogen for the production of nitric acid, which in turn will be used to make ammonium nitrate for the fertiliser trade.

Some Problems Solved

Repairing Ball Mill Bearings

Routine overhaul revealed that the journal bearings of a large ball mill were badly ridged and had worn to a slightly conical shape. According to normal repair methods, the mill would have been dismantled and conveyed to a machine shop where the journals would be resurfaced by means of special cutting tools. Since in this case the mill weighed about 10 tons, this solution was to be avoided.

The solution adopted was to jack up the mill and use a portable grinding head to resurface the journals. The head consists of a split pulley and frame carrying banks of grinding stones which can be adjusted as the grinding proceeds. The pulley is belt-driven and the stones are adjusted constantly until a uniform and parallel surface is prepared. This equipment enabled each journal to be made good with a tolerance of a 2 thousandth of an inch within three days, which is less than half that required by the more conventional machine-shop methods. The apparatus used for this rapid repair is service is provided by Nicol & Andrew of known as the "Master Hone" and the Glasgow.



Economy from Fuel Survey

The picture here is one of a plant with an increasing demand of steam for process and space heating. As a result of a survey carried out by N.I.F.E.S., a steam accumulator was installed and greater attention paid to operation and maintenance to ensure that the steam-raising plant gave of its very best. In a department where drums were reclaimed the fitting of a hydraulic device for drum and barrel cleaning, which could be operated from the standard steam supply, produced a saving of approximately £450 a year. These modifications were made at the B.B. Chemical Co. Ltd., Leicester.